The Launch of the
JAGUAR XK8
Luxury Sports Car

MANUFACTURING EXCELLENCE FOR XK8
THE CHALLENGE FOR JAGUAR

1
Advanced Product Engineering Design Concepts to Meet Market Requirements and Customer Expectations

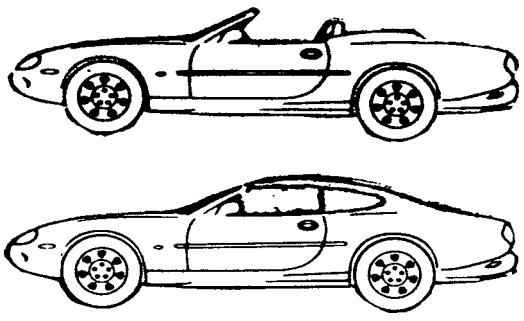
2
Integrated Cross-Functional Team Working Throughout Project Lifetime at Every Level

3
Advanced Quality Tools and Techniques and Trained People to Ensure Effective Team Working

4
World Class Quality Suppliers Participating as Full Partners

5
Integrated Manufacturing Quality & Vehicle Launch Process,

MANUFACTURING EXCELLENCE FOR XK8



XK8 —
A WORLD CLASS PRODUCT

SELLING IN 70 MARKETS WORLD WIDE

THE LAUNCH OF THE JAGUAR XK8 LUXURY SPORTS CAR

Overview

The new Jaguar XK8 Luxury Sports Car demonstrates the highest standards of excellence in British Engineering and represents a further significant advance for Jaguar, building on the foundation established for the XJ6 saloon car project.

Jaguar's engineering expertise, working in close collaboration with its suppliers, has enabled a world class-leading product to be launched which demonstrates all the attributes of 'Manufacturing Excellence'.

The Company's competitive performance in world-wide markets is expected to be much enhanced by the launch of the XK8 with significant improvements in quality and process efficiency throughout manufacturing operations. Customer satisfaction levels are planned to surpass leading German and Japanese competitors.

This submission by Jaguar Cars Limited for the 1996 Manufacturing Excellence Award identifies five key elements which, taken together, constitute the extent of the challenge to the Company and therefore the basis for this application.

These five key elements are:

1. **The XK8 advanced product engineering and design concepts** necessary to meet and exceed customer expectations across highly competitive world-wide markets with an emphasis on profitable growth for the business.

2. **Integrated team working at every stage of the project** and across all functions in the Company to ensure consistency in working methods, and to optimise programme objectives for cost, timeliness and quality.

3. **The introduction of creative quality tools and techniques**, including computer aided information technologies in order to achieve high levels of design and process assurance, with a strong emphasis on training people in new skills.

4. **The selection of a world class supplier base** and their involvement throughout the project lifetime to achieve world class standards of quality and delivery.

5. **The manufacturing, quality and launch processes** applied to ensure consistent delivery of product in line with design specifications and quality objectives using appropriate metrics.

The chart opposite provides an overview of the XK8 challenge. Sections 1 to 5 which follow, provide a fuller explanation of the way in which all engineering and technical areas of Jaguar have responded to the challenge to achieve Manufacturing Excellence for its new XK8 Luxury Sports Car.

Functional / Mechanical

- 4.0L Na AJ-V8 Engine
- 5 Speed Electronic Auto Transmission
- Speed Sensitive Power Steering
- Traction Control
- Seatbelt Pretensioners (front)
- Superlocking
- Power Latching Hood
- Auto Dropping Glass With One Shot Down
- Steering Wheel Mounted Switches
- Variable Ratio Steering
- Adaptive damping

Exterior

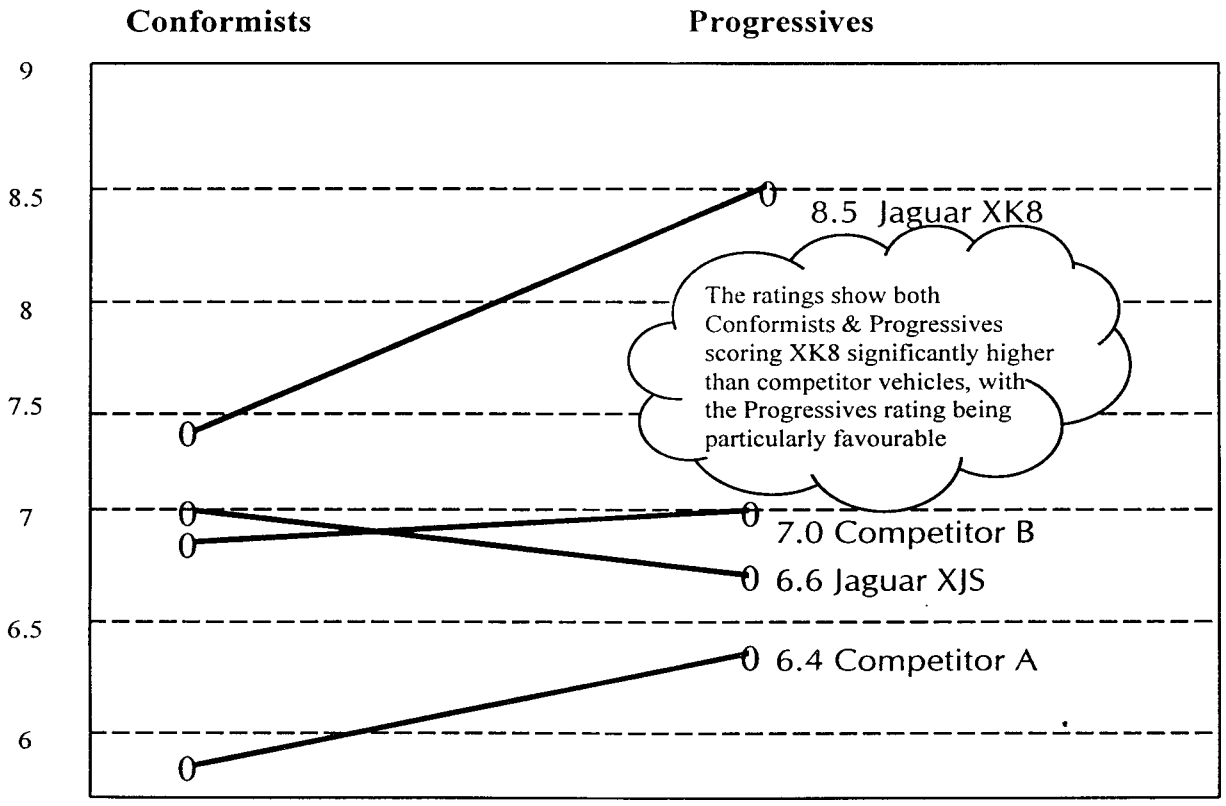
- Body Side Mouldings
- Telescopic Headlamp Powerwash System
- Electrochromic Exterior Mirrors

Comfort and Convenience

- Garage Door Opener
- Electric Foldback Mirrors
- Particle Filtration in Air Con. System
- Illuminated Entry
- Entry/Exit Tilt Away Elec. Adj. Column With Memory
- Glass Mounted Electrochromic Interior Mirror
- Removable driver Footrest
- Blade Mounted Washer Jets
- Heated Windshield
- 4 Button Remote With Headlamp Convenience/Panic & Boot Unlock Feature
- Cup Holder
- Height Adjustable Front Seat
- Coin Stowage
- Sports/Classic Trim

XK8 New Features

Overall Exterior Ratings: Coupe



Styling Clinic Results

1. Advanced Product Engineering Design Concepts

The XK8 programme was conceived during a difficult trading period for Jaguar following take-over by Ford when the focus was on protecting the saloon core business to maintain volumes and revenue.

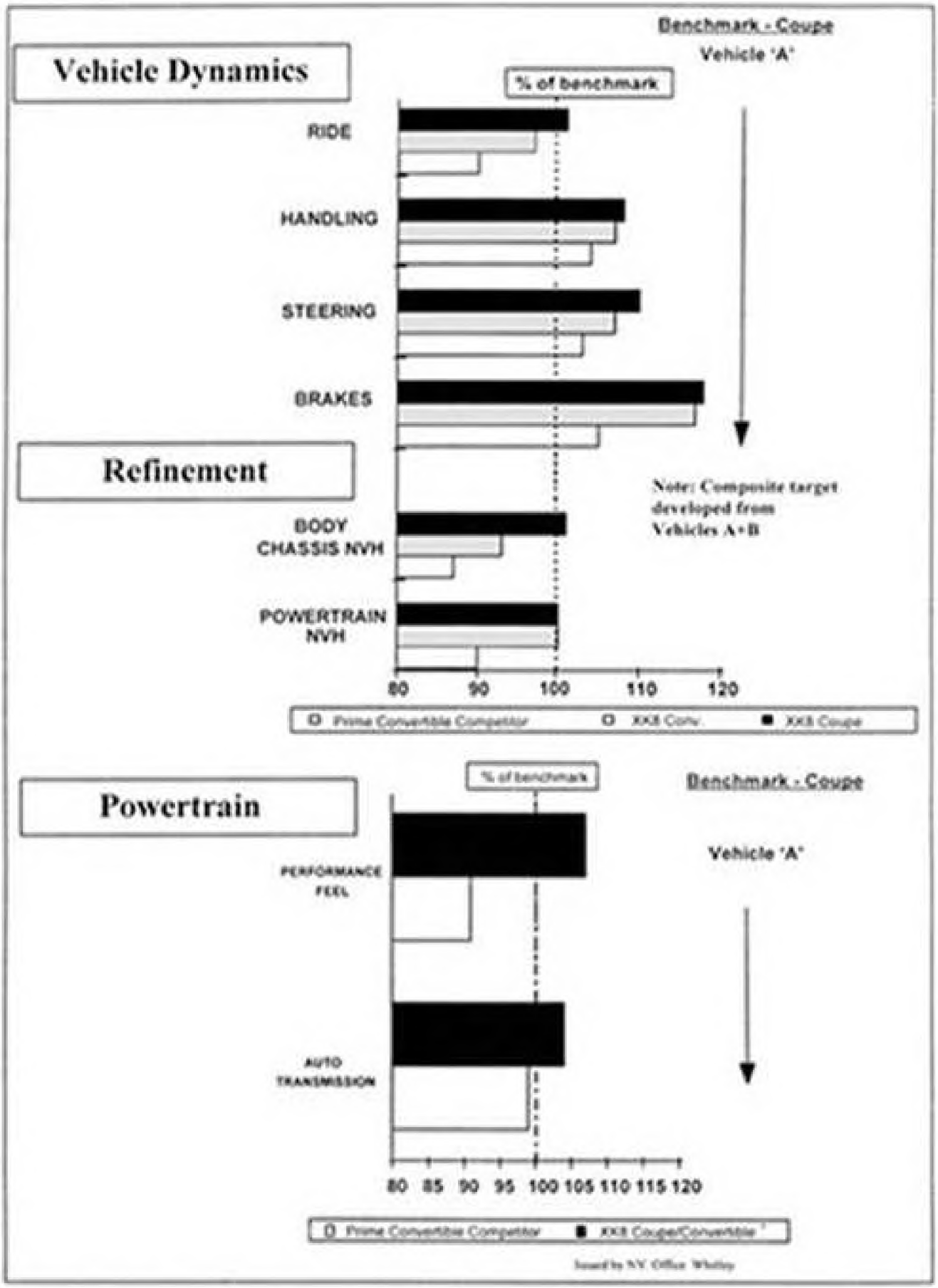
The challenge therefore for the XK8 team was to convince management to invest heavily in a relatively small volume sports car project to build on the success of the XJ6 saloon programme and relaunch Jaguar as a producer of high quality, exciting, technically innovative cars to compete fully against Japanese/German manufacturers. The brief was simple: to produce a car that would meet or exceed customer expectations and achieve high levels of customer satisfaction.

XK8 being the first new sports car to be introduced by Jaguar for over 21 years required extensive up front planning to understand the market environment and establish the 'voice of the customer' in support of the market positioning and programme/product definition. This included competitor ride and drives/benchmarking to establish key vehicle attributes and market research clinics in America/United Kingdom to select the all important style concept.

The result is the most complex programme ever undertaken by Jaguar Cars, with over 1700 new parts, which protects Jaguar's traditional strengths of style, refinement and craftsmanship, responding to the world market need for quality, feature levels. At launch the line up will include two bodystyles, coupe and convertible, with a class leading exciting style, an all new Jaguar 4.0 litre AJ-V8 engine with 5 speed automatic transmission and numerous new features, including a power latching convertible hood operable on the move , power tilt steering column with memory tilt away, global closing locking system, variable ratio steering and adaptive damping to provide XK8 with a class leading product specification to satisfy the requirements of 70 markets across the world.

The luxury sports sector is very susceptible to new product action and changes in economic climate. XK8 market research showed that the class leading style and product image would increase appeal beyond the current owner body and put Jaguar in a strong position to exploit the projected segment growth. XK8 scored very high absolute clinic ratings which were significantly higher than facing competition supported by high buying interest. Respondents stating that they were over 3 times as likely to buy the XK8 than XJS and 50 % more likely to buy XK8 than the next best competitor.

New technology has been introduced to meet the demanding product specification and package constraints imposed by the low sleek style including multiplexed wiring systems with low and high speed communication networks and the use of lightweight alloys for the front suspension crossbeam, propshaft and hood frame to meet the weight targets.



XK8 Functional Image Results

Aggressive programme objectives were established for key vehicle attributes including quality, ride and handling, performance and economy, weight and aerodynamics by benchmarking the 'Best in Class' competitors and projecting stretched job 1 targets based on agreed product/technological advancements. Buy in to and monitoring of the target status via the '18 panel chart metric' was achieved through the 'heavyweight' Project Team who were empowered to make decisions on behalf of their base department. Functional images are set to provide a significant uplift over XJS to all of the key dynamic attributes of the vehicle. The AJ-V8 engine and new 5 speed automatic transmission provide best in class performance feel coupled with high levels of refinement. Overall ride and handling balance, a traditional Jaguar strength also achieves BIC. All other attributes are amongst class leaders at launch.

A key driver for XK8 was to achieve significant improvements in all aspects of quality through fundamental changes to the design and manufacturing philosophy by ensuring greater emphasis on quality planning throughout the programme. Process improvements also formed an integral part of the quality improvement plan.

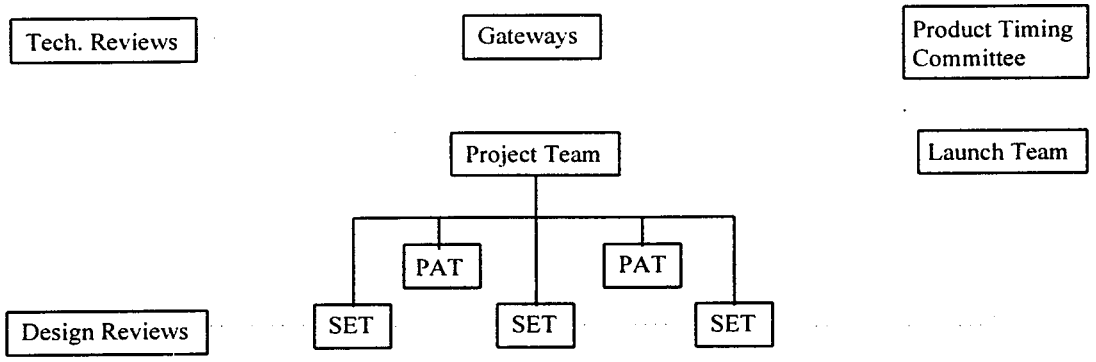
XK8 projections for 'Things Gone Wrong' and 'Repairs' reflects an improvement of 44% over last job XJS and is fully competitive with facing competition. The ultimate measure of XK8 success in improving quality will be the customer satisfaction rating which is for 95% of customers not experiencing 'TGW' and 90% of customers with 'TGW' to be very or completely satisfied at 3 months in service.

The XK8 programme was constructed against a background of falling XJS sales but favourable clinic results forecasting sales well above peak XJS volumes based on the exciting style/product/feature package being proposed.

Aggressive investment costs for tooling, in house facilitisation and engineering costs were set to protect programme profitability. The profitability of the programme was most sensitive to volume fluctuations and was therefore approved against a conservative volume forecast.

The variable cost of the vehicle was determined by the affordability of the investment in relationship to the pricing; the target was to achieve all of the quality, feature, function and regulatory requirements for a cost no greater than the out going XJS.

The Structure



Representatives

	Product Eng.	Manuafct. Eng.	Production.	Styling	Prog. Office.	Finance.	Supply.	Vehicle Eng..	Compon. Supplier	Quality	Timing	Project Team	SET Leader
Project Team	O	O	O	O	O	O	O	O	○	O	O		○
Gateways	●	●	●	●		●	●	●		●	●	O	
Tech. Reviews	●	○										O	O
Product Timing Committee	●	●	●			●	●	●		●	●	●	
Design Reviews	●											O	O
SET	O	O	○	○	○	O	O		O	O	○		O
PAT	○	○	○	○	○	○	○	○	○	○	○	○	○
Launch Team	●	●	O				O	O	O			●	○

Key :- ● = Senior Management, O = Empowered Representative, ○ = As Required

Processes & Computerised Systems

WCT / Gateways	New/Developed
ICEM Surf.	Developed
Surface Verification	New
Design Reviews	New
PROMPT	New
SPRINT	New
Targets to Objectives	Developed
DVPSOR	Developed
Early Supplier Initiatives.	Developed
PTIS	Developed

Programme Health Metrics

Parts status for next build
Functional Images
DVPSOR (Design Verification and Sign-Off Report)
Open Concerns
18 Panel objectives
Deliverables - Last Gateway
- Next Gateway
SET status.

NB: Details and evidence shown in the Evidence book

Integrated Cross Functional Teams

2.Integrated Cross-Functional Team Working

Given the extremely challenging product and timing objectives outlined, Jaguar needed to extend its thinking on programme management. A Cross-functional team was set up consisting of managers or empowered representatives from all key disciplines. Their objective was to complete the detailed product definition for formal approval and take the programme from approval to job 1 in 32 months. A challenge finally achieved in just 30 months.

Team Structure: The Project Team was structured in line with Jaguar World Class Timing Process (JWCT) with each representative responsible for their functions deliverables. Deliverable achievements were measured at gateways held at key intervals. By aligning the empowered team with the new product process flow (JWCT) cross-functional barriers were removed and a more simultaneous approach was promoted.

The design of the product was split into key systems and components, each of which had a Simultaneous Engineering Team (SET). Each SET was allocated a sub-set of the programme objectives for which it was responsible and progress was monitored monthly at a Design review. Here the Project team joined with Design management to resolve any cross-SET issues and to guide the design. In a similar way the Project management responsibility was devolved to Programme Action Teams (PAT) which took responsibility for specific disciplines or problems. These continued the Cross-functional empowered theme particularly during the early stages of the programme.

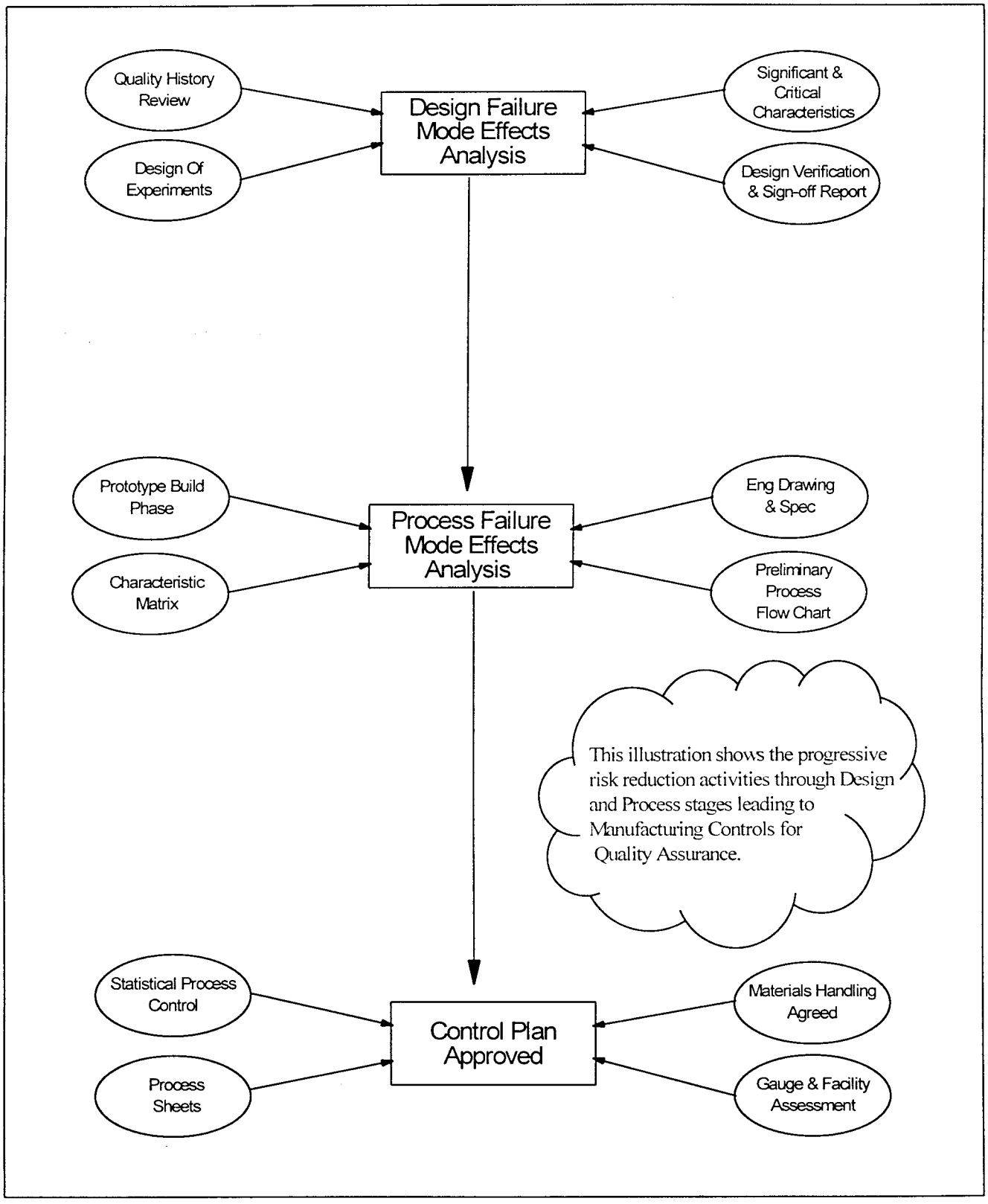
16 months from Job 1 a Launch Team was formed. This team had responsibility for ensuring the project went into production on time, on budget and most importantly achieving the required quality objectives.

The Process: The timing challenge required a delivery time which was shorter than previously achieved by Jaguar and was consistent with Bench marked world leaders. At all levels of the company there was a need to adopt changed and new processes. Starting at the company level with JWCT new processes were developed and integrated to ensure delivery was achieved. Processes have been documented for ISO 9001 approval (achieved Dec '94).

Computerised Information Technology has been utilised to provide tools to achieve the programme goals and cross functional communication. PROMPT and SPRINT provided prototype material control and production specifications, whilst PTIS provided metrics and detail status reports by linking five individually dedicated systems. The advantage of having single source data available to all, ensured common understanding and focus.

Metrics were used at all levels in the programme structure and at all stages to measure progress toward objectives. These ranged from SET status sheets to Programme objectives to problem resolution. A selection of these are listed opposite.

Summary:
The innovative and interactive team and process development has achieved the required objectives and puts Jaguar amongst the worlds leaders for quality, product and timing. The Project Team model developed for XK8 has been further adopted and developed for later Jaguar Product changes.


Quality History Review
Design Of Experiments
Design Failure Mode Effects Analysis
Significant & Critical Characteristics
Design Verification & Sign-off Report
Prototype Build Phase
Characteristic Matrix
Process Failure Mode Effects Analysis
Eng Drawing & Spec
Preliminary Process Flow Chart
This illustration shows the progressive risk reduction activities through Design and Process stages leading to Manufacturing Controls for Quality Assurance.
Statistical Process Control
Process Sheets
Control Plan Approved
Materials Handling Agreed
Gauge & Facility Assessment

Key Advanced Quality Planning Activities

3. Advanced Quality Tools and Techniques

Product quality is no longer a source of competitive advantage. It is a prerequisite for sustaining a position in the market. The introduction of advanced quality tools and techniques were therefore critical to the success. of the programme.

Initiatives new to XK8 are described below :-

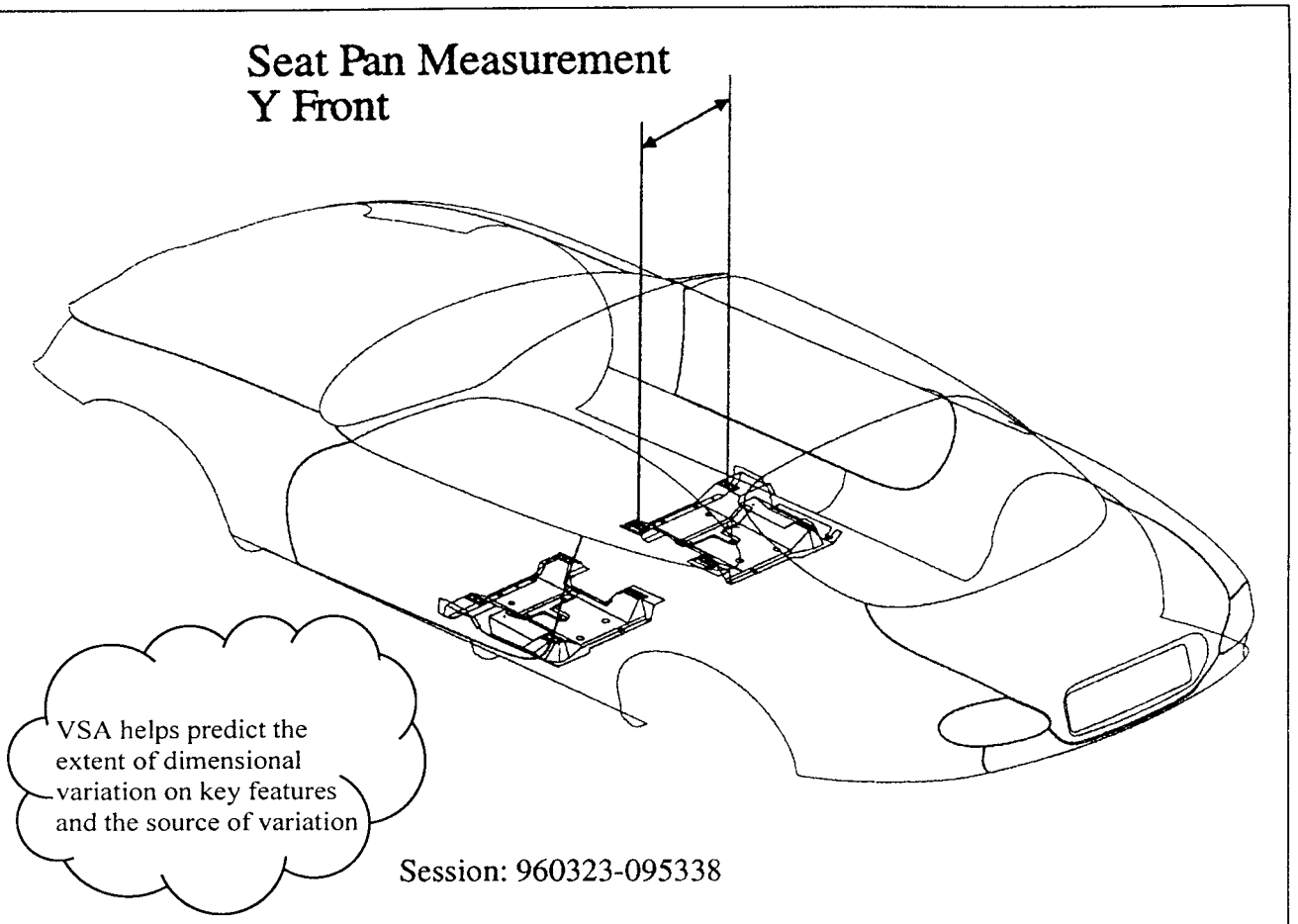
An Advanced Quality Planning Steering Group, chaired by the Programme Manager and comprising representatives from all the major disciplines, were responsible for overseeing all quality activities. This Group identified the need for a more detailed and informative timing plan outlining quality sign-off dates within the overall World Class Timing process.

Simultaneous Engineering Teams (SET's), were formed for all major sub-systems. For the completely new AJ-V8 engine, a Concept Design SET was formed, followed by seventeen individual SET's, all reporting to the Core Programme Team.
Design of Experiments (DOE) techniques were employed for many features of the engine, and complete and thorough Design and Process Failure Mode Effect Analyses (FMEAs) were carried out.

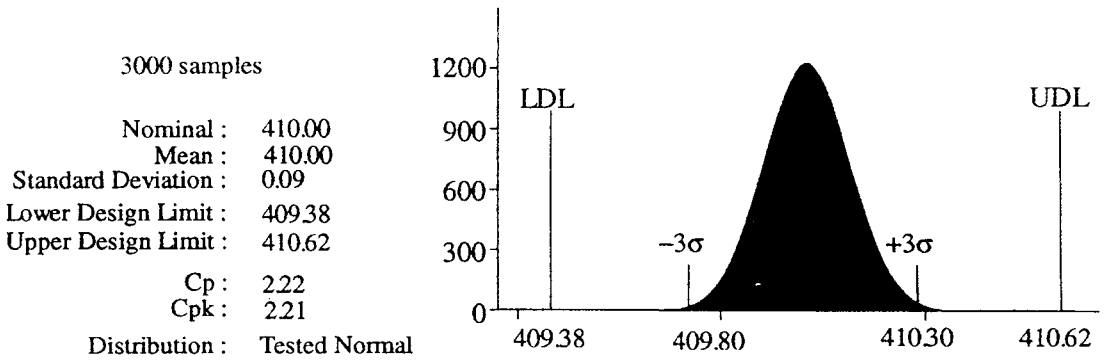
Benchmarking Competitors Vehicles using Touch Zone Analysis. This process is intended to reflect the impressions that a potential customer would experience when first looking at and sitting in the vehicle. Emphasis is placed on the immediate impressions created rather than the detailed engineering or ergonomic analysis. Full results of this exercise were displayed in the Jaguar Engineering Centre, and photograph booklets were issued to all relevant areas.

A programme of Design and Process FMEAs was drawn up for critical systems, resulting in the identification of Significant and Critical Characteristics. These were subsequently included in the Control Plans drawn up by the component suppliers and, where appropriate, by Jaguar production personnel. These characteristics were monitored during the prototype build phases of the project - resulting in higher levels of product quality from these early-build vehicles.

Training for the XK8 Project Team was heavily biased towards the new quality initiatives. Whenever possible, the majority of the Team members were trained as a group, and in particular this applied to the foundation course for the Ford EQUIP training (**E**ngineering **Q**uality **I**mprovement **P**rogramme).
This course includes modules on problem solving (TOPS-8D), process management, FMEA, Design of Experiments and Quality Engineering and Quality Function Deployment. The full team attended a residential Team Building course, and this was seen to result in improved team relationships as the project proceeded.


Seat Pan Measurement
Y Front
VSA helps predict the extent of dimensional variation on key features and the source of variation
Session: 960323-095338

YFRONT True length between the seat pan front weld nuts



	Sample	Est		Sample	Est
% < Low Limit	0.00	0.00	Low	409.70	409.72
% > High Limit	0.00	0.00	High	410.31	410.28
% Out of Spec	0.00	0.00	Range	0.61	0.56

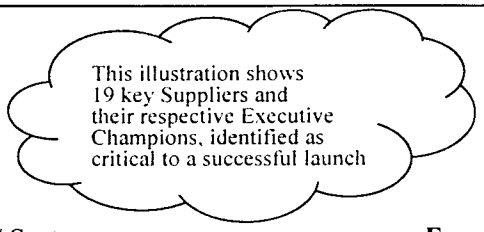
95% C.I. for % Out of Spec : 0.00 to 0.00

Example Of a Typical VSA Measurement

A total-vehicle dimensional control discipline (No-Adjust Car Build, or NACB) was introduced which recognises and manages variation during the design, manufacture and assembly of the vehicle in order to meet customer quality expectations in appearance and function, without requiring operator fit and finesse.

Variation Simulation Analysis (VSA) techniques were used to predict the product and process variation before tooling was committed. This involved the build of a three-dimensional model representing part geometry, location systems, assembly processes and component variability. The model identified areas of concern which were addressed by design changes at an early stage.

The results of these quality initiatives will be finally measured by the vehicle owners after the model is launched. However, internal audits and vehicle assessments show the consistent progress to meet Job 1 quality targets, (page 11f) for both Coupe and Convertible.



Supplier	Compt/ System	Executive Champion
ACD	Body system	**C.Tivey**
KARMAN	Hood frames	**K.Giles**
MARLEY/MAGNA	Facia	**C.Tivey**
SCHADE	Glazing seals/ retainers	**K.Lodge**
AI (LEAR)	Door casing/Trim casing	**D.Hudson**
ARVIN	Exhausts	**M.Beasley**
CAMFORD	Wishbones/links/brake disks	**K.Giles**
ITT	Frt/ Rr Bumpers	**D.Hudson**
KOSTAL	Column & Switches	**K.Lodge**
LEAR	Seating	**C.Tivey**
OGIHARA	BIW	**K.Giles**
PBM	Crossbeam/ crossmember	**M.Beasley**
SOMMER MASLAND	Carpet/Boot trim	**M.Beasley**
AUTOMOLD	runk trim	**M.Beasley**
UTA	Harnesses	**D.Hudson**
GKN DRIVESHAFTS	Propshafts	**M.Beasley**
DANA	Drive unit	**M.Beasley**
TECALMIT	Fuel pipes	**C.Tivey**
ZF	Transmission/St Racks	**R.Dover**

XK8 Suppliers: Executive Champions

4. World Class Quality Suppliers Participating As Full Partners

Quality deliverables were defined for XK8 suppliers as an integral part of the design brief or quotation request. Competitive quality criteria defining the product in terms of best competitive practice were identified and provided to potential suppliers.

Supplier participation was planned throughout the design process and manufacturing launch phases. Suppliers were fully integrated in the Simultaneous Engineering teams and worked closely with Jaguar personnel on design detail and quality planning.

The challenge was to select key suppliers very early in the programme, integrate these suppliers into the engineering activity and work together with them through launch reviews to achieve a quality product, delivered to the trackside at the right time.

Early sourcing: Initiatives were targeted at procurement of early prototype components from the development and ultimate production source. A total of 39 key systems were agreed as early sourcing priorities, based on four criteria - quality critical, long lead time, high value and technology change. Where practicable, World Class Q1 suppliers were chosen. Sourcing was completed 33 months before Job 1.

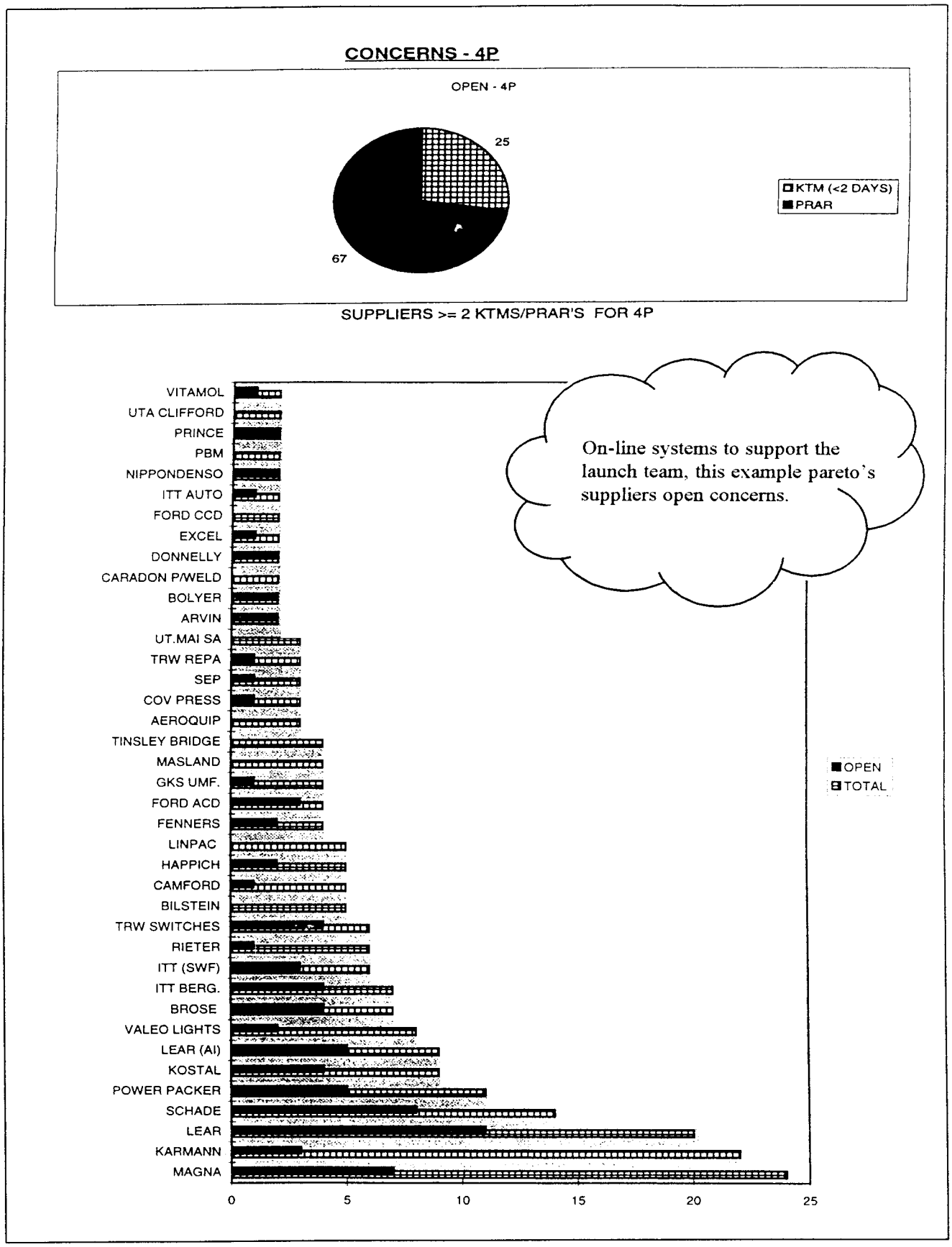
Supplier participation: Vendors of key components supplied full-time colocated support to the launch team, for all the builds at Browns Lane.

Executive champions: To enhance the launch support process, Executive Champions were appointed, 16 months before Job 1, to review progress with 19 suppliers of key components and systems identified as critical to the vehicle launch. A further 77 suppliers of medium risk components were selected for regular launch reviews with the Buyer and Supply Technical Assistance Engineers.

Launch reviews targeted areas of risk within the suppliers' own launch plans, and so required discussion on training, recruitment, facilities, tooling and sampling plans. The aim of these reviews was to focus supplier senior management effort on robust planning. The status of launch reviews were included in the Supply weekly metrics.

Advanced Quality Planning: In addition to the 39 key components and systems, a further 41 were identified for significant AQP activity. Throughout the design stages Engineering Quality worked proactively with the design areas and suppliers, to establish significant and critical characteristics and identify current car customer concerns from External Quality and Warranty data that needed to be considered during the design definition.

Supplier Technical Assistance (STA) were responsible for the downstream supplier AQP responsibilities in respect of capability studies and control plans. STA Engineers reviewed the suppliers' AQP and sample status on a regular basis. STA weekly metrics reported overall status.



On - line systems developed to monitor supply progress

Logistics: Manufacturing Engineering identified special logistical requirements for 235 parts, supplied by 40 suppliers, ranging from unique packaging to Just-In-Time trackside delivery. Inventory management benefits include reduced handling, stockholding and scheduling. Electrical data interface resources were increased to handle the increased traffic.

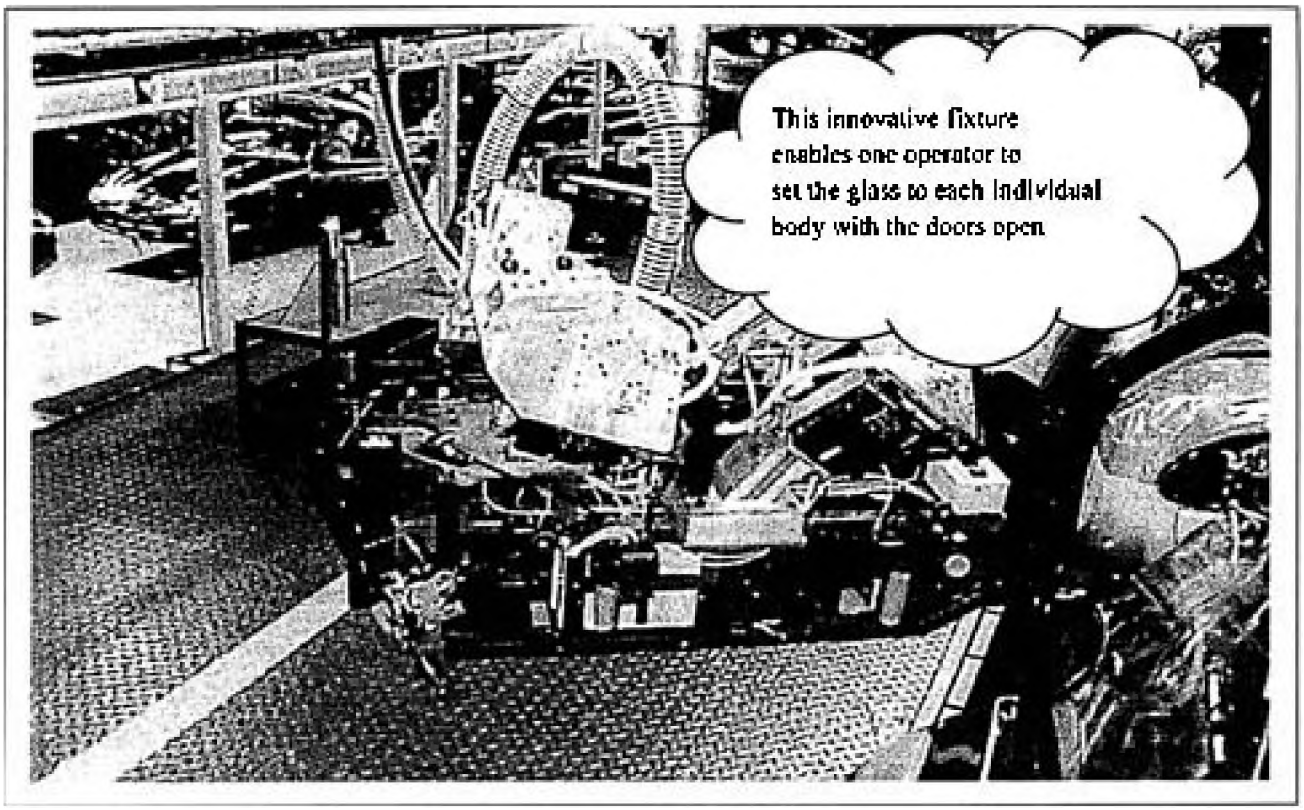
Sample monitoring/control: Production Purchasing metrics focused management attention on supplier launch, quality and sample status. Published weekly, it provided performance, trend and key issue information.

Sample data was provided by the Production Tracking Information System (PTIS). STA metrics provided key task monitor and AQP data, launch data came from the supplier reviews.

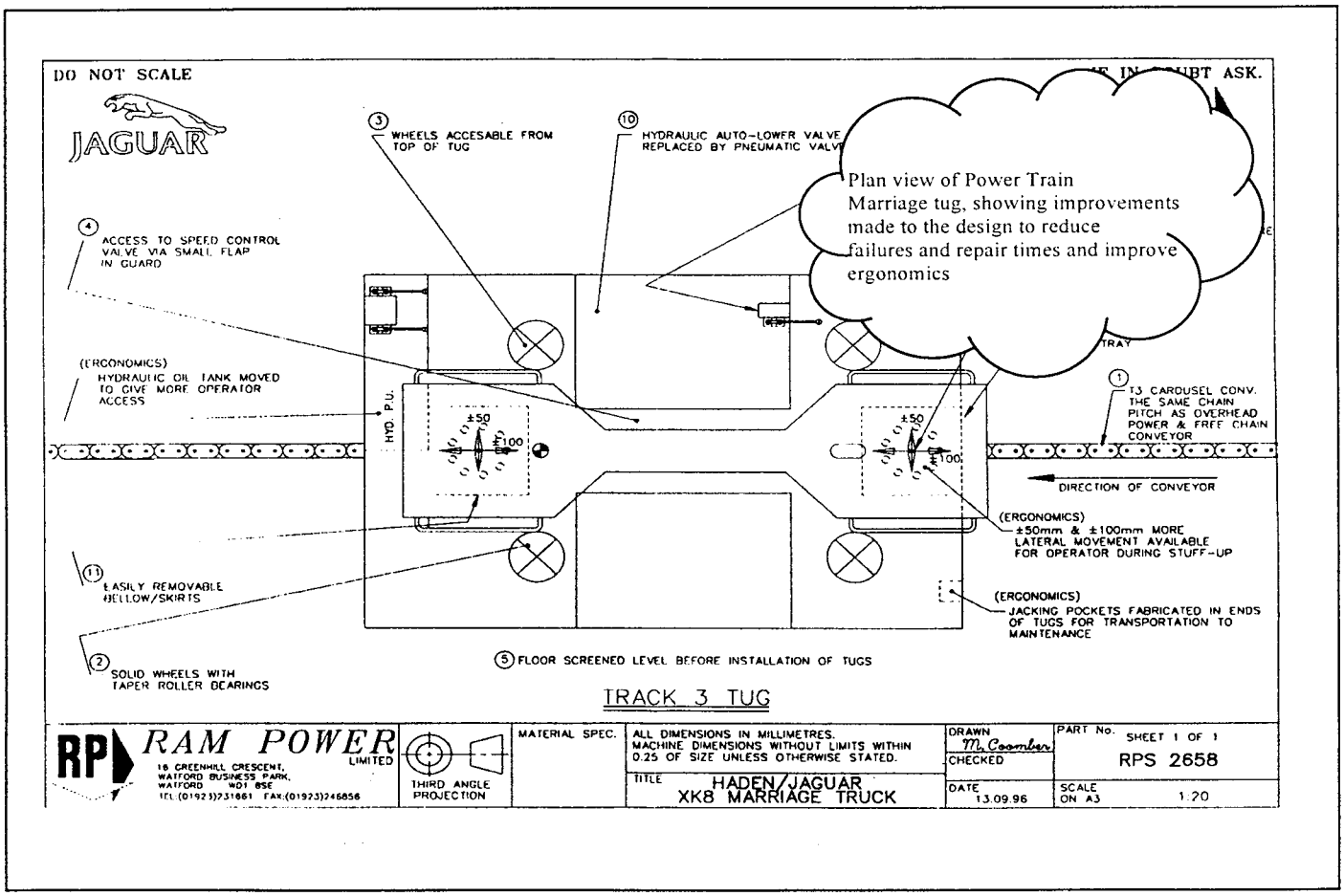
Summary

The 'team' approach of supplier/manufacturer relationships has ensured rapid response to change, reduced costs and brought the product to market on time. Suppliers have improved their own process to meet our needs and therefore placed themselves in the best position for future business in the industry.

The use of metrics as a 'health check' on the project has been carried forward into all new programmes and model year changes.



Best Practices and Innovation: XK8 Door Glass setting.


DO NOT SCALE
JAGUAR
3 WHEELS ACCESABLE FROM TOP OF TUG
10 HYDRAULIC AUTO-LOWER VALVE REPLACED BY PNEUMATIC VALVE
4 ACCESS TO SPEED CONTROL VALVE VIA SMALL FLAP IN GUARD
(ERGONOMICS) HYDRAULIC OIL TANK MOVED TO GIVE MORE OPERATOR ACCESS
HYD. P.U.
±50
±100
Plan view of Power Train Marriage tug, showing improvements made to the design to reduce failures and repair times and improve ergonomics
TRAY
1 13 CAROUSEL CONV. THE SAME CHAIN PITCH AS OVERHEAD POWER & FREE CHAIN CONVEYOR
DIRECTION OF CONVEYOR
(ERGONOMICS) ±50mm & ±100mm MORE LATERAL MOVEMENT AVAILABLE FOR OPERATOR DURING STUFF-UP
(ERGONOMICS) JACKING POCKETS FABRICATED IN ENDS OF TUGS FOR TRANSPORTATION TO MAINTENANCE
11 EASILY REMOVABLE BELLOW/SKIRTS
2 SOLID WHEELS WITH TAPER ROLLER BEARINGS
5 FLOOR SCREENED LEVEL BEFORE INSTALLATION OF TUGS
TRACK 3 TUG
RP RAM POWER LIMITED
18 GREENHILL CRESCENT, WATFORD BUSINESS PARK, WATFORD WD1 8SE
TEL:(01923)231661 FAX:(01923)246856
THIRD ANGLE PROJECTION
MATERIAL SPEC.
ALL DIMENSIONS IN MILLIMETRES. MACHINE DIMENSIONS WITHOUT LIMITS WITHIN 0.25 OF SIZE UNLESS OTHERWISE STATED.
TITLE HADEN/JAGUAR XK8 MARRIAGE TRUCK
DRAWN M. Coomber
CHECKED
DATE 13.09.96
PART No. RPS 2658
SHEET 1 OF 1
SCALE ON A3 1:20

Manufacturing Involvement: Reliability & Maintainability improvements designed into the facility by Maintenance teams

5. Integrated Manufacturing, Quality & Vehicle Launch Process

This element describes the initiatives introduced within each manufacturing plant from early prototype stages through to Job 1 to develop XK8 to world class quality, timing and cost targets.

Challenge

XK8 represents the most demanding product launch in the company's history : two new body styles, suspension, power unit, interior and exterior trim and radically new electrical architecture.

Quality targets were set to exceed XJS levels at launch. An affordable cost structure based on conservative sales volumes demanded high levels of investment efficiency and cost control.

The challenge was to harness the skills and knowledge at every level, building on the processes developed for the 1995 Salon car launch.

Exploiting World-wide Best Practices. Comparative analyses within Jaguar, Ford and our competitors were carried out to identify best launch practices, manufacturing processes and facility strategies.

From analysis of strengths and weaknesses of 1995 saloon launch, the XK8 team improved key launch processes such as windnoise and water integrity management. "Chunk Teams" allocated to specific vehicle areas provided improved focus.

Benchmark visits to Ford car plants highlighted process opportunities and led to innovations such as the XK8 door glass setting fixture. Studies of competitors products led to the inclusion of auto-drop door glass, delivering major capability and quality improvements.

Manufacturing Involvement And Ownership At The Earliest Stages. Full time Production Operation support commenced three years before Job 1. For the first time, Production Plants were represented on the Project Core Team.

From the fourth quarter 1993, Production Operators, Supervisors and Engineers participated in key Simultaneous Engineering Teams, i.e. fuel system, sealing and interior trim. From EP build (Oct 94) production operators supported ALL build phases. Initially 10 Group Leaders, 11 Rectifiers and approximately 40 operators (for key operations) inputted for build feasibility and to gain early process appreciation. The number of production operators participation increased progressively through the build phases.
Maintenance tradesmen were involved in detailed facility design with equipment suppliers.

Major improvements in reduced component complexity, manufacturing feasibility and equipment reliability and maintainability were achieved.

XK8 Functional Post Build Plan for Browns Lane

PP No.	3	8	2	4	5	16	18	15	366	13	19	21	30	20	11	340	341	17	31	22	32	28	302	303	281	283	36	282	57	33
Model	Cp	Cp	Cp	Cv	Cv	Cp	Cp	Cv	Cv	Cv	Cv	Cp	Cp	Cp	Cp	Cp	Cv	Cv	Cv	Cv	Cp	Cv	Cp	Cv	Cv	Cv	Cp	Cp	Cp	Cp
Drive	LHD	LHD	RHD	LHD	LHD	RHD	RHD	LHD	RHD	LHD	RHD	LHD	LHD	RHD	LHD	LHD	LHD	LHD	LHD	RHD	LHD	LHD	RHD	LHD	RHD	LHD	LHD	RHD	RHD	RHD
Market	USA	USA	UK	USA	USA	UK/E	UK	USA	UK	USA	UK/E	USA	UK	UK	USA	USA	USA	USA	GER	UK	GER	UK	UK	GER	JAP	USA	USA	UK	UK	UK
On Track	12/2	14/2	19/2	19/2	20/2	21/2	22/2	26/2	26/2	27/2	27/2	28/2	28/2	29/2	01/3	04/3	04/3	05/3	05/3	06/3	07/3	08/3	11/3	11/3	12/3	12/3	13/3	13/3	14/3	15/3
Track Build	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Elec Prove	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Water Test	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
OTR	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
C F C	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5								0.5	0.5	0.5
Road Test	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1											1	1	1
VCATS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1													1	1
R/Road x10			0.5	0.5		0.5			0.5	0.5		0.5			0.5														
P/Shop		2		2			2		2		2		2	2															2	
F Line/CAL	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1														1	1
Hydropulse	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5														5	0.5
Smoke Test	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5														5	0.5
NOVA - C	2				2			2							2															
Emissions			0.5	0.5		0.5				0.5		0.5																		
Elec Prove	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5														2.5	2.5
R F I checks		0.5	0.5	0.5			0.5	0.5		0.5		0.5		0.5																0.5
Days Reqd	15.5	16.0	15.0	17.0	15.5	14.5	16.0	16.0	16.0	15.0	15.5	15.0	15.5	16.0	16.0	16												15.5	15.5	14.0
Days Avail	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16											16	16	16
PDI	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Drive Team	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
P T S	08/3	12/3	15/3	15/3	18/3	19/3	20/3	22/3	22/3	25/3	25/3	26/3	26/3	27/3	28/3	29/3	29/3	01/4	01/4	02/4	03/4	04/4	05/4	05/4	10/4	10/4	11/4	11/4	12/4	15/4

Shows for each Prototype vehicle (columns) the number of planned days allocated for validation of each "off track " process.

Prototype Build: Exploiting every vehicle to validate key processes.

Launch Team Daily Schedule: Venue: XK8 Launch Team room, GEC Block.

0730 hrs:	Start up meeting: Agenda:	New issues
0800 hrs:	Exceptions Meeting: Agenda:	Progress Outstanding Issues
	0800 hrs:	B.I.W.
	0830 hrs:	Trim
	0900 hrs:	Chassis
	0930 hrs:	Power Unit
	1000 hrs:	Electrical
	1000 hrs:	Vehicle Office (Weekly meeting only)
	1030 hrs:	Purchase (Weekly meeting only)
1100 hrs:	Product Change Instruction Meeting: Agenda:	Engineering Releases
1600 hrs:	Washup Meeting (Track build meeting)	

Change Control: Rigorous daily routine

Simulated Production Builds And Teamwork. Five key principles represented major advances for XK8:

- Production teams made responsible for building prototype vehicles, exposing problems as early as possible. Familiarisation for operators commenced 18 months before Job 1. Progressive off-track, sledge build and on-track vehicle builds took place 6-12 months earlier than previous launches.

- Every prototype vehicle was exploited to validate parts of the post-build process - including Paint Repair, Road Test, Electrical Validation test and twelve other processes. This "early view" provided ample time to fix problems.

- Special builds, involving key groups to focus specific risk areas:

    * Suppliers emphasis build : viewing component assembly into vehicles.

    * "Fresh eyes " builds : Assessing detailed build process

    * Slow build : for process and serviceability verification.

- Early introduction and verification of key facilities utilising XJS build : eg. Power Train Marriage System.

- Achievement of representative track speed before Job 1. Operators were used to XJS volumes : half the track speed of XK8. By re-assigning the track and gapping every other XJS the track speed was doubled. XK8 prototypes were then built on the same track, at representative cycle times.

Total Engineering Change Control. Previous launch experience had proved the importance of managing late engineering modifications. For XK8, all changes following early prototype build were controlled by the Launch Team. This comprised 130 full time Product, Manufacturing and Production Engineers, Operators, Purchase Agents, Finance Analysts and On-site Supplier Representatives. The team effectively eliminated departmental barriers, and created the sense of urgency necessary for rapid change.

A relentless daily routine handled over 8600 launch issues, 2000 engineering releases and co-ordinated the build of 141 prototype vehicles.

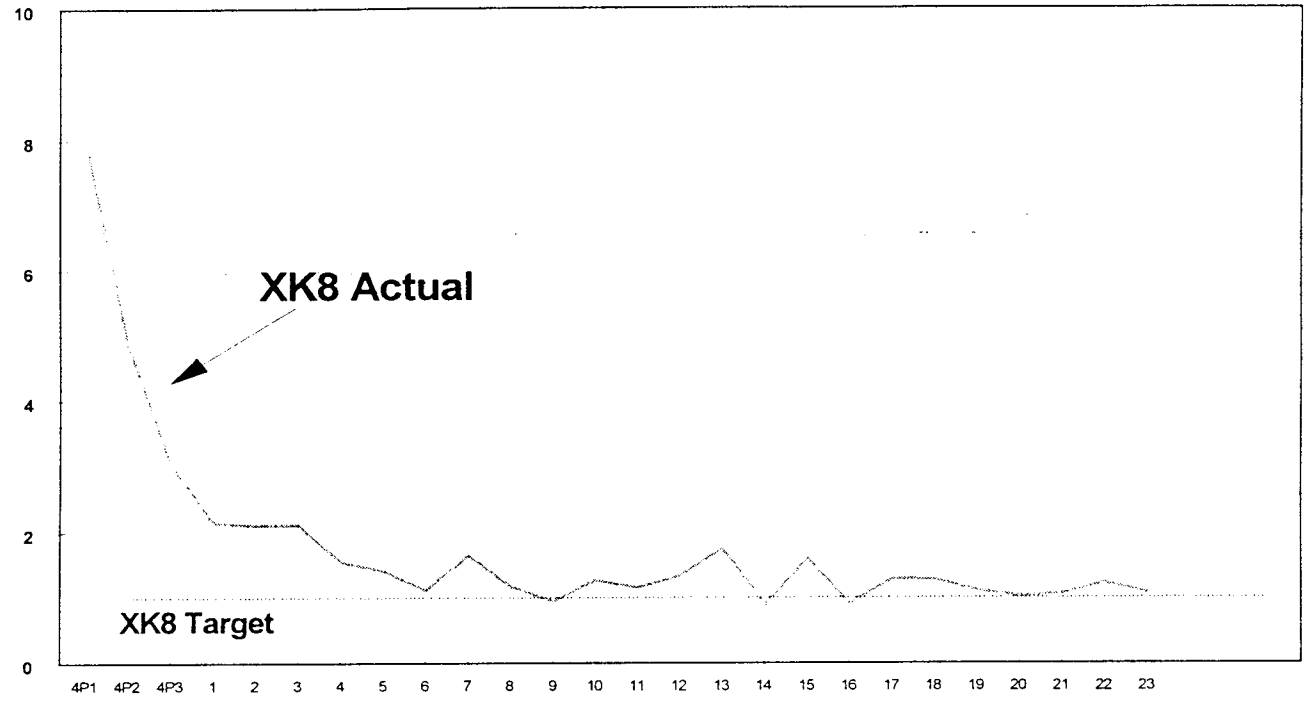
Progress was monitored against key metrics (page 11) at formal launch reviews.

Total Cost Control. The financial function within the Launch Team was to advise on cost affordability of change.

Immediately a change was identified it was logged and costed. Where cost increase were involved the launch philosophy was to protect the customer and quality levels, but to find ways to make the change affordable

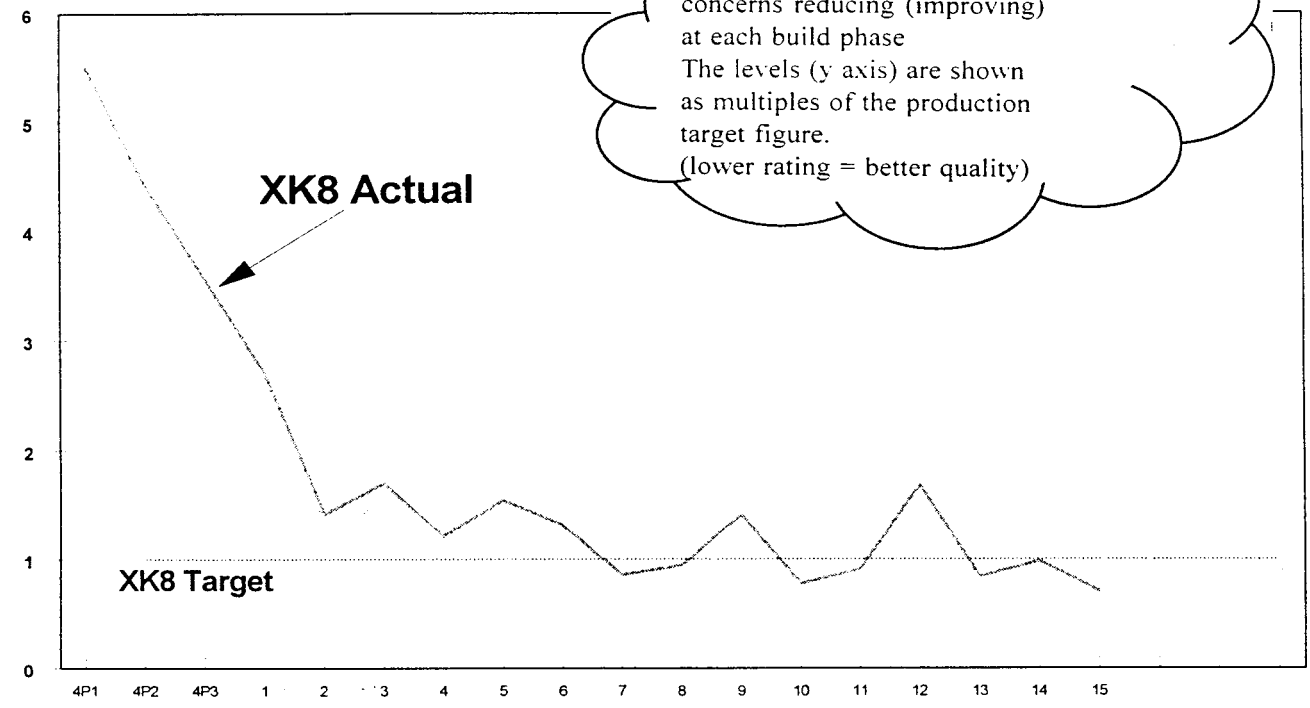
Prototype to Volume Build

Coupe



(Volume Build in Groups of 5 Cars)

Convertible



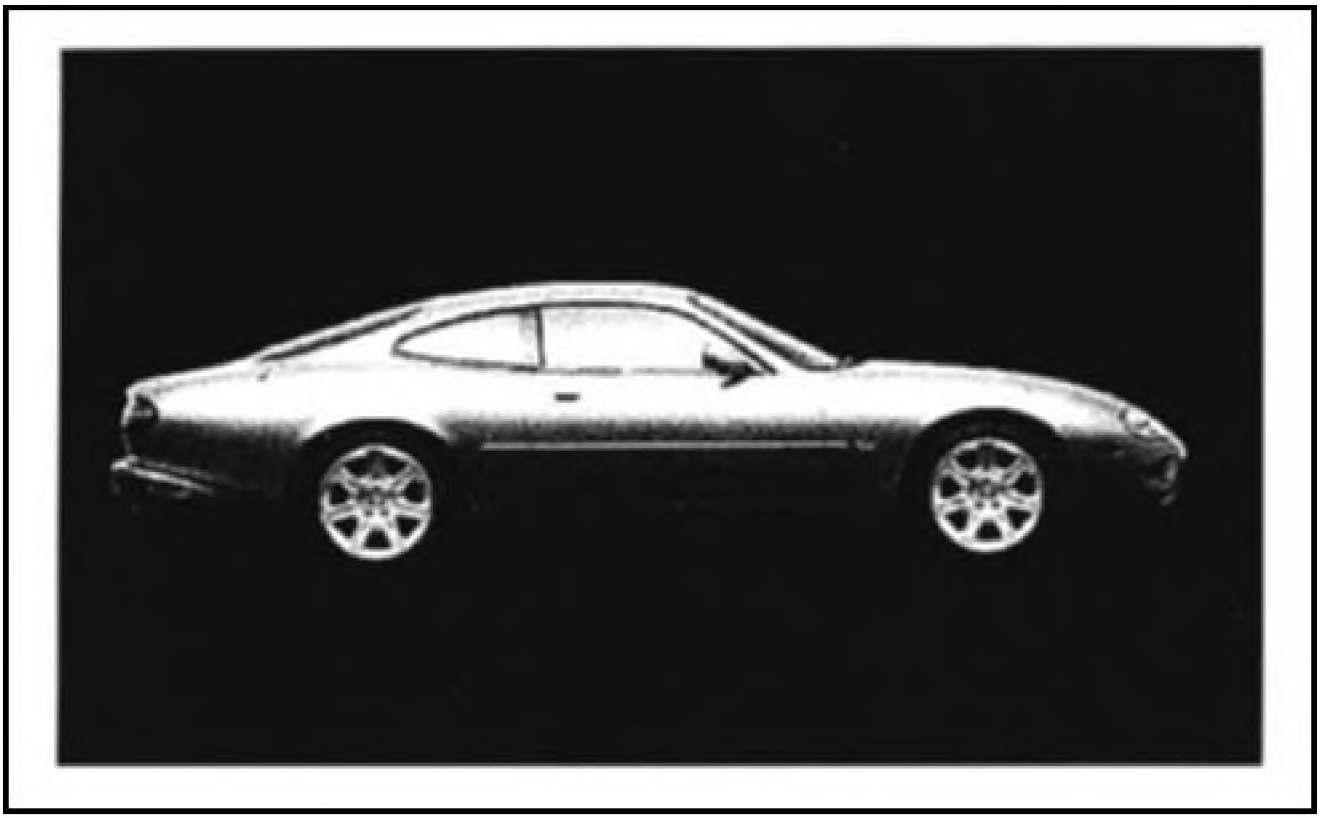
Charts show the level of concerns reducing (improving) at each build phase
The levels (y axis) are shown as multiples of the production target figure.
(lower rating = better quality)

(Volume Build in Groups of 5 Cars)

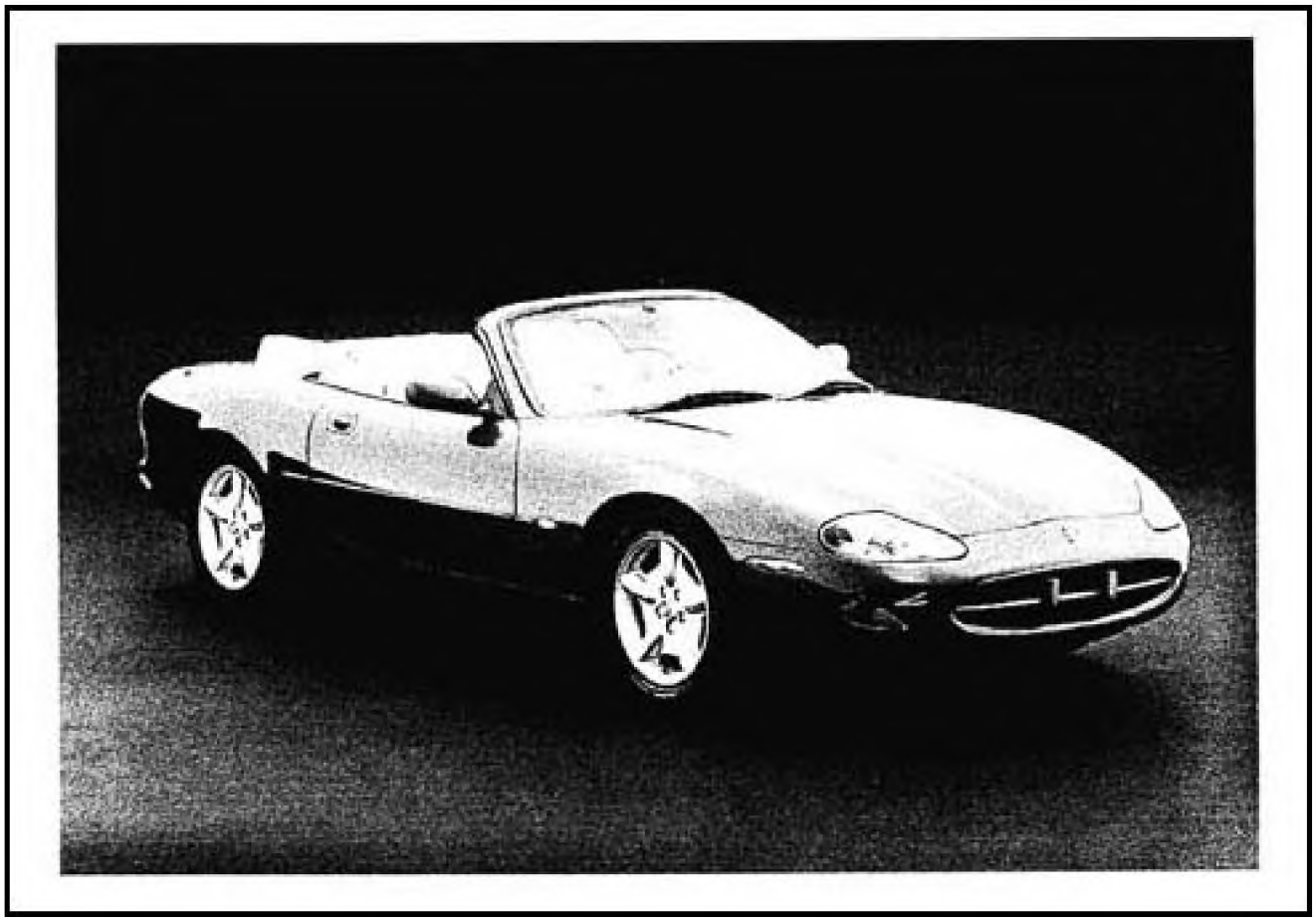
Product Control reported total vehicle cost which was fed into the profit model for confirmation of affordability. This enabled Finance to be pro-actively involved in the change process rather than reporting cost after change.

Metrics targets established by benchmarking best-in-class opposition were set for each build phase:

- Right-First-Time and Statistical Process Control characteristics measured at each build zone.
- Vehicle Assessment audits of bodies and completed vehicles.
- Customer Focus Centre providing immediate feedback of assembled vehicle quality.
- Windnoise, Water Squeaks and Rattles : in-plant assessment on all vehicles.
- Problem closure rate - targeted at establishing the fixes for 70% of problems, within two days.
- Functional images : status of vehicles against refinement, performance etc.
- Manufacturing readiness : facility, process and training status.



JAGUAR XK8 Coupe



JAGUAR XK8 Convertible

Conclusion

Jaguar believes that **the XK8 project fully meets the criteria for 'Manufacturing Excellence'** and represents a substantial step forward in manufacturing competitiveness for the UK, including the automotive component supplier sector.

Extensive scientific research into future market requirements has ensured a highly specified product which is set to substantially lead in customer satisfaction in the very competitive world-wide markets for luxury sports cars.

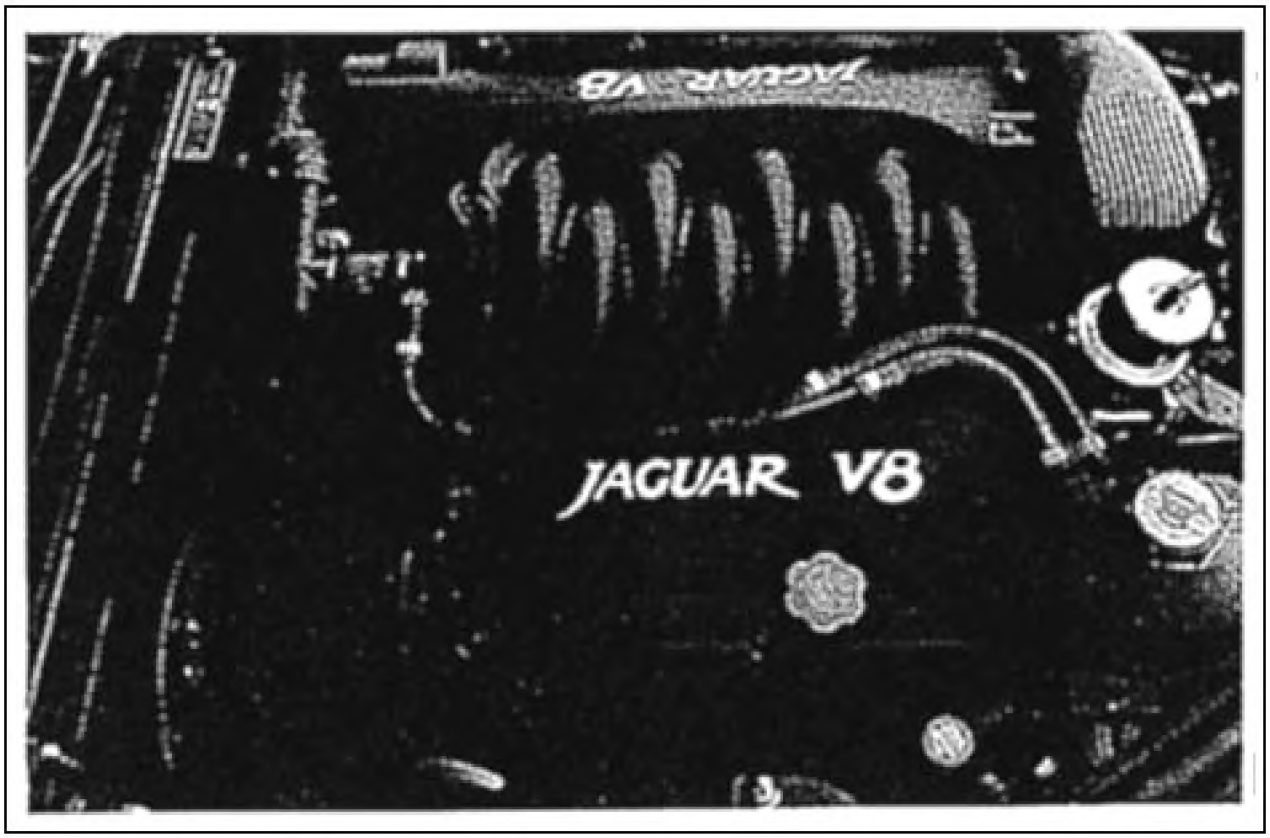
The application of advanced design and engineering has taken Jaguar's product development expertise onto a higher level of excellence. This expertise has ensured delivery of a robustly engineered and profitable new car which meets or exceeds all its targets for cost, quality and performance.

Although highly complex in specification, the XK8 is nevertheless **simple for the customer to use** and meets the highest **world-wide standards for safety, exhaust emissions levels** and **recyclability**.

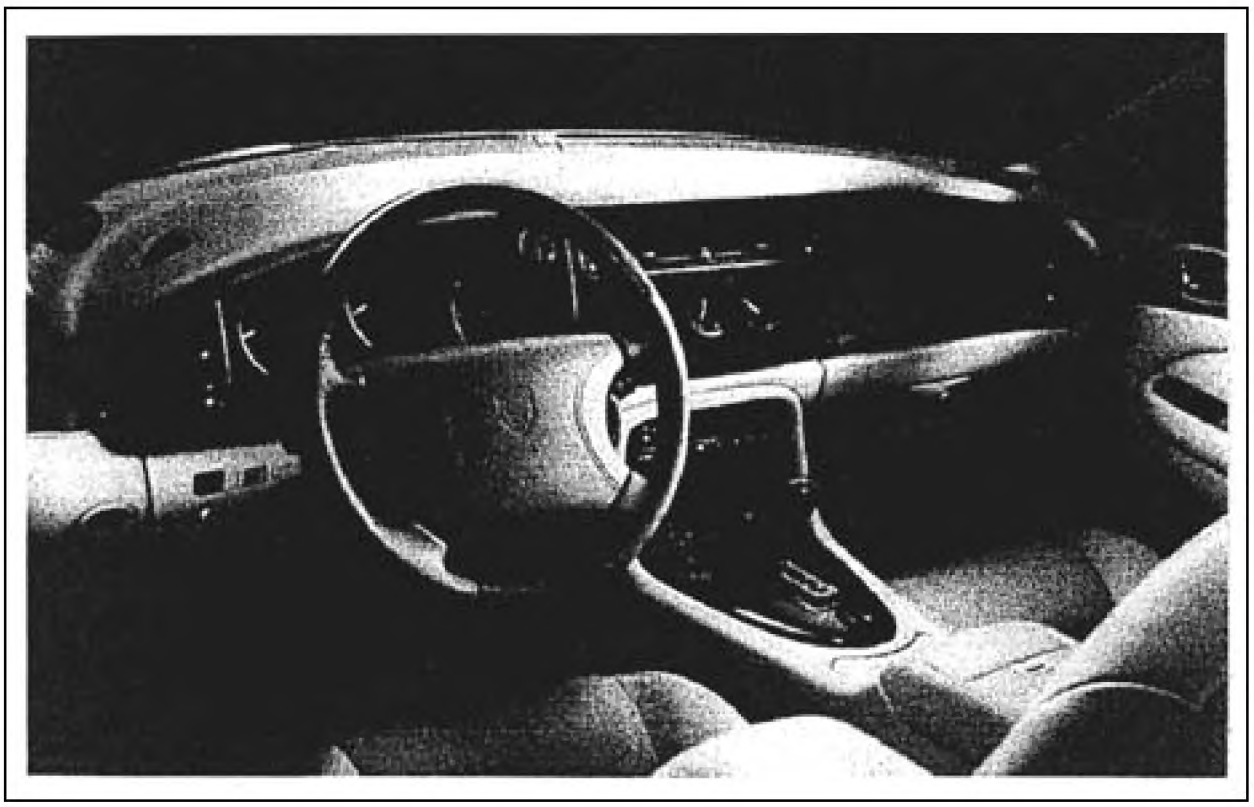
Cross-functional project teams have operated at every level from overall programme management to the detailed **simultaneous engineering** of individual components. These teams have operated to a new set of **project management disciplines** designated as the **'World Class Timing Process'** achieving much reduced project lead times compared with traditional methods. This extensive and demanding set of standards has now been institutionalised across all design and development functions at Jaguar and has formed a significant element of the Company's **certification to the ISO 9001** standard.

The careful selection of an **international supplier base with a strong emphasis on UK sourced components** has been essential to the achievement of quality and cost objectives. New advances have been made in just-in-time delivery techniques, taking advantage of the spacious new layout in the manufacturing areas enables point of fit sequenced delivery (P.O.F.D.) of components, reducing in-process stock and material handling .

At every stage in the product delivery process, **performance objectives and metrics have been established** and used to control the project. New **engineering analysis tools and statistical techniques** have been introduced with extensive operator training to ensure that the quality of the XK8 will surpass that of leading German and Japanese competitors.
The introduction of **new processes and statistical techniques into Manufacturing** (such as no-adjustment car build and variation simulation analysis) has built on the quality and efficiency improvements achieved over recent years for saloon cars. **The Mobilisation of shop floor teams and the extensive training** of all those involved in the manufacture of the XK8 has ensured total commitment to quality and consistency in delivering product to engineering specification with reduced times for customer order satisfaction.



The new JAGUAR AJ-V8 Engine



JAGUAR's XK8 Classic Interior

THE XK8 ENGINE MANAGEMENT SYSTEM AND ELECTRONIC ENGINE CONTROL MODULE

Mark Gallagher B.Eng. C.Eng MIEE

Abstract

The increasing demand for feature enhancements on passenger vehicles combined with more stringent emissions and legislative requirements world-wide has lead to a high level of complexity within engine control modules, associated emission control hardware and equally important, software.

This paper briefly explains how the functions of the AJV8 engine control work and how the diagnostics form an integrated part of the system design.

Introduction

The XK8 is powered by an all new Jaguar 4-litre V8 engine known as the AJV8. Its Engine Control Module (ECM) in addition to governing 'standard' engine functions such as fuel injection, ignition timing and closed loop fuelling also controls an electronic throttle body, knock sensing, variable valve timing, engine cooling fans and high speed real time serial communications with other control modules using the CAN protocol to manage traction control and shift quality etc. In addition, it continually adapts to take account of engine to engine variation, component and engine ageing and any default actions that may be required. With this increased complexity comes the need for a diagnostic system to allow faults to be detected quickly, accurately and be rectified easily should they occur.

Several of these functions already exist on previous engines and engine control modules. However, the AJV8 is the first ECM to command such an extensive range, and as such is the most complex and technologically advanced controller Jaguar has ever launched.

For the purpose of this paper the functions of the AJV8 Engine Management System (EMS) can be viewed as comprising:

1. Engine Control Module
2. Throttle Control
3. Ignition Control
4. Fuelling Control
5 Diagnostics

It should be noted that these systems have a great deal of inter dependency.

We shall start with an overview of the EMS.

Mark Gallagher is with the Electrical Engineering Department of Jaguar Cars Ltd.

EMS Overview

An engine management system consists of a number of actuators and sensors with a central control unit, the engine control module (ECM). The ECM receives inputs from the sensors and operates closed loop control of the engine by driving the actuators to a required state. High speed real time communications with other control modules (for example the Anti Lock Brakes Controller) allow the integration of functions such as cruise and traction control. Figure 1 below shows some of the control exercised by the engine control module together with some of the sensors and actuators that make up the engine management system.

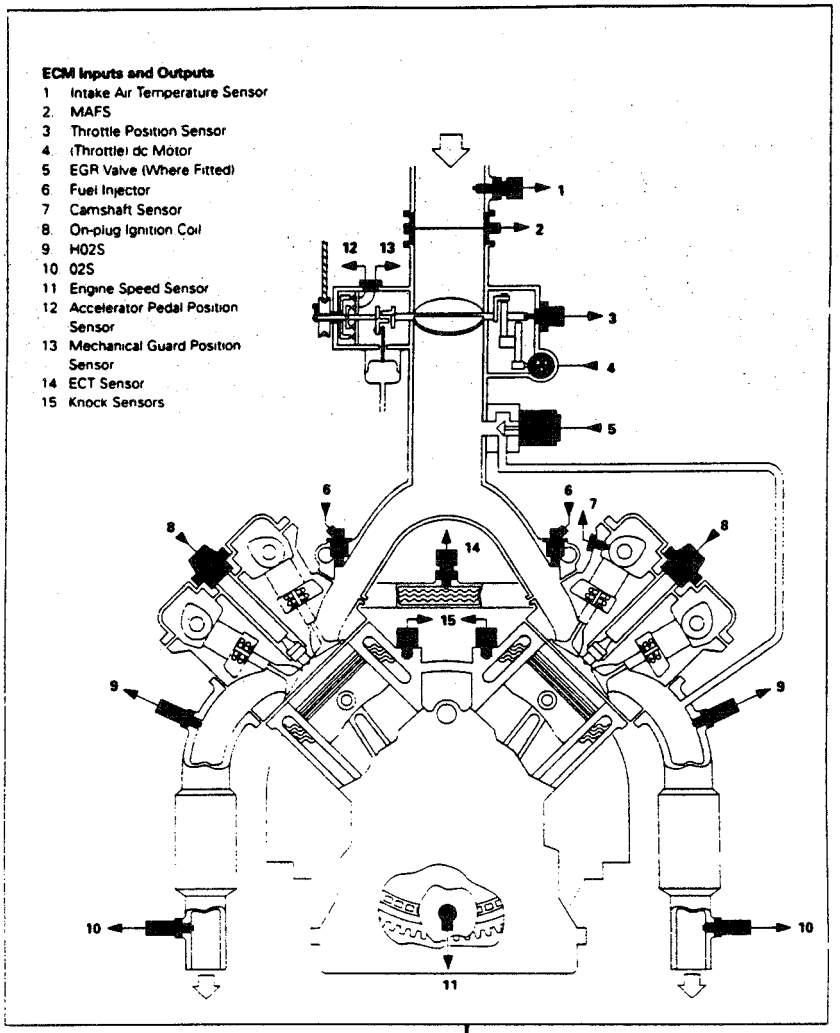
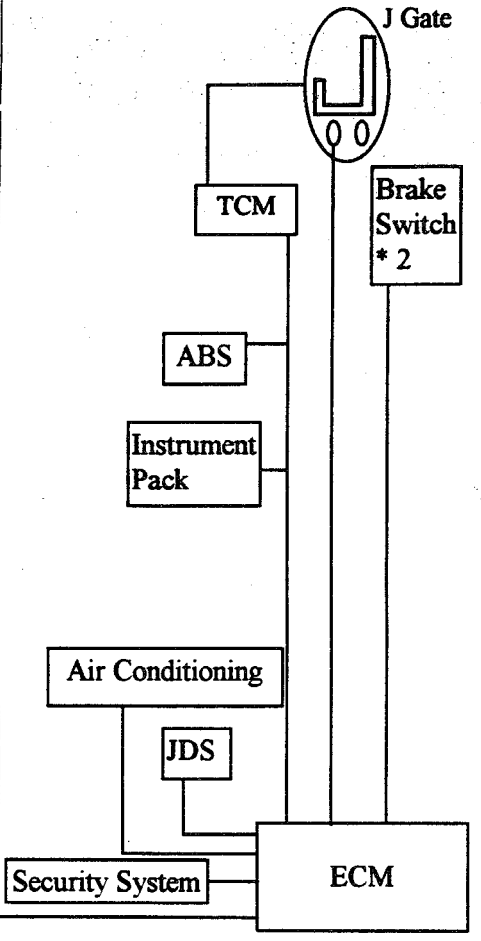


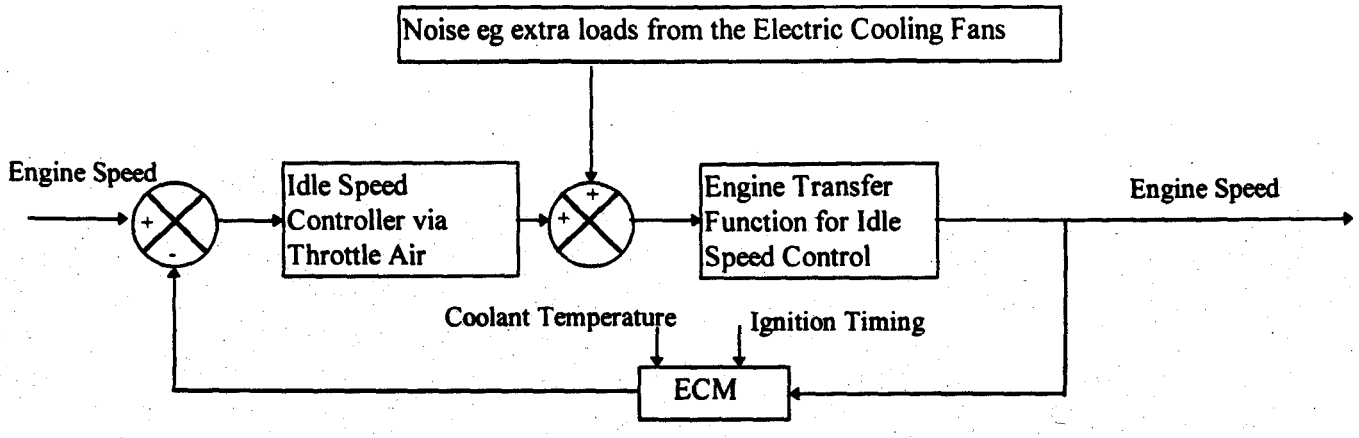
Figure 1: EMS Overview



The closed loop control operated by the ECM/EMS is usually affected when perturbations and noise (usually in the form changing loads on the engine) alter the operating conditions of the engine which are detected via the engine sensors. The control of the actuators is then altered to compensate for the new conditions. The AJV8 engine management controller typically operates two (Proportional and Integral) or three (Proportional, Integral and Derivative) term classical control over sub systems. A 3 term PID controller for idle speed control is used with proportional and integral terms controlling the air flow via the throttle blade, whilst changes to the ignition timing act as a derivative term due to the excessive transport lag of the air control.

Figure 2 shows a simplified closed loop control block diagram. The transfer function is not shown but is described in Ref 1. The model will contain two state variables, inlet manifold absolute pressure and engine speed. There are three inputs, throttle angle, ignition advance and the load torque.

Figure 2: Idle Speed Control Closed Loop Control Block Diagram

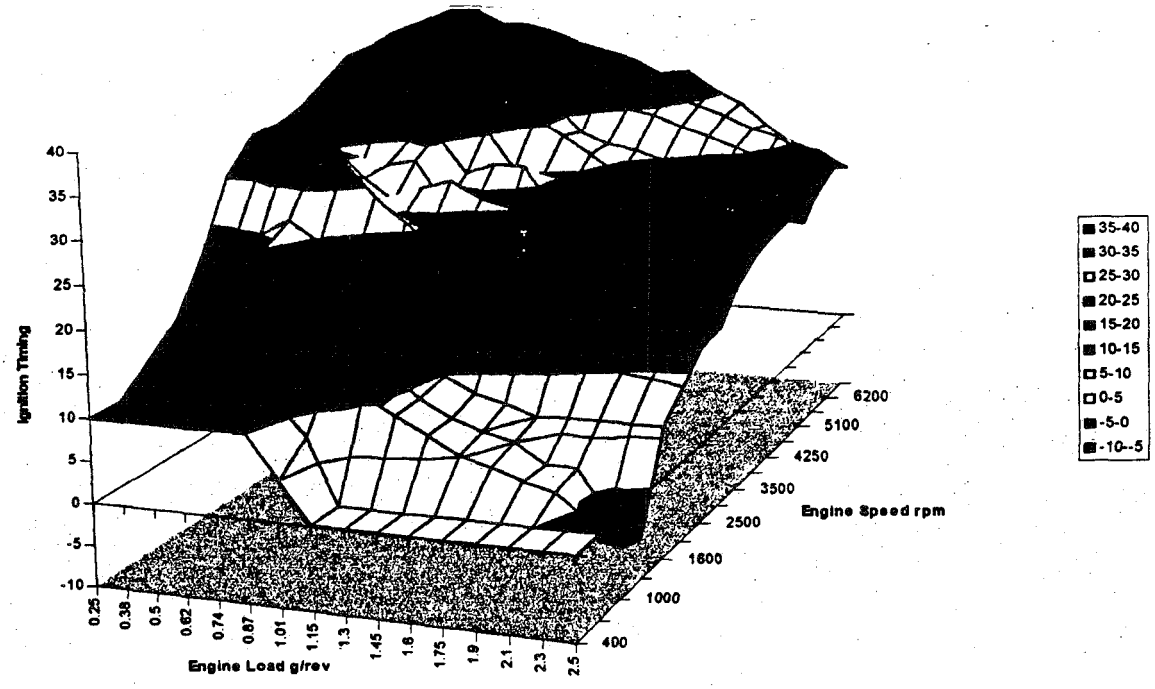


To determine the required actuator operation the ECM uses a series of look up tables which are usually referred to as maps. Figures 3 and 4 show a typical ignition map.

Figure 3: Part of the base ignition map

Engine Load g/rev \ Engine Speed rpm	400	700	1000	1300	1600	2000	2500	3000	3500	4000	4250	4500	5100	5700	6200	6800
0.25	9.9	9.9	13	16	22.1	30.1	34.1	34.1	35	37.1	39	39	39.5	39.5	39.5	39.5
0.38	9.9	11	16	17	23	30.1	34.1	34.1	31	35.9	39	38	37.6	39.5	39.5	39.5
0.5	9.9	12	19.1	20	24.9	32.9	32	31.3	27	32.9	35	35.9	35.9	37.1	38	38
0.62	9.9	12	20.9	24.9	27	32.9	29.6	27.7	28.2	30.1	34.1	35	35.5	37.1	37.1	38
0.74	9.9	12	20.9	24	24.5	32.9	26.6	25.2	28.9	31	32.9	34.5	35	35.9	35.9	37.1
0.87	9.9	12	17.9	20	20.9	28.9	24	27	23.3	26.1	30.5	32.9	33.6	34.5	34.5	35.9
1.01	5	8	13.9	15.1	17.9	26.1	23	28.2	23.5	27.5	25.4	31	31.5	33.6	33.6	35
1.15	0.1	0.1	11.1	12	13.9	23	22.1	26.1	20.2	27.5	24.7	28.9	28	32	32.4	34.1
1.3	0.1	0.1	9	9	9.9	19.1	20.2	25.2	19.8	22.6	24	26.6	26.6	30.1	31.5	32.4
1.45	0.1	0.1	7.1	7.1	8	17	18.1	23.3	19.8	20	23	24	25.9	29.4	30.8	32.9
1.6	0.1	0.1	5.2	5.9	7.1	15.1	17.2	20.9	17.7	19.1	20.9	23	24.9	28.2	29.6	30.5
1.75	0.1	0.1	4.1	5	5.9	13	16	19.8	16	20.5	21.9	23.3	23.8	27	28.4	28.9
1.9	0.1	0.1	2.9	2.7	6.2	11.1	12.7	18.1	18.1	21.2	22.8	23.5	22.6	25.6	27	26.1
2.1	0.1	0.1	2	2.7	6.2	9.9	11.8	16.7	16.3	19.5	21.2	21.6	20.7	24.2	26.1	23.8
2.3	0.1	0.1	-1.1	-2.5	6.2	9.5	11.8	15.5	14.1	18.1	19.1	20.9	18.4	22.1	23.8	23
2.5	0.1	0.1	-3.9	-5.1	6.2	9	11.8	12.5	16	17.9	19.1	19.3	17.4	20.2	22.1	20.9

Figure 4: Base Ignition Map



A better understanding of the operation of an EMS can be understood when compared to that of a standard carburettor system. This is explained in the simple example below.

Carburettor System

1. Driver estimates the engine temperature based upon ambient temperature and time since the engine was last run.
2. Driver uses the choke to compensate for wall wetting of the fuel on the cold cylinder.
3. Driver starts engine
4. Driver re-estimates the engine temperature and attempts a re-start.
5. Driver sets off on the journey as required and re-estimates the engine temperature based upon time since start, road speed and driving style, and re-adjusts the choke.

Engine Management System

1. ECM receives an input from the coolant temperature sensor giving an accurate measurement of engine temperature.
2. ECM uses a look up table to determine the amount of starting fuel required.
3. Driver cranks engine
4. Engine starts

5. ECM receives a new input from the coolant sensor every 30ms and automatically adjusts the fuelling as the engine warms up.

It should be noted that the driver of the carburettor vehicle will usually be able to achieve a first time start after a learning period, during which time more careful changes to the start fuelling can be made. This learning is another feature of an engine management system as it adapts for engine to engine variation and engine ageing.

1. Engine Control Module

The Engine Control Module (ECM) manages all primary engine functions including fuelling, ignition and an electronic throttle body for air control. It also controls secondary systems such as knock sensing (see later), variable valve timing (see later), engine cooling fans, high speed serial communications with other control modules (CAN) and On Board Diagnostics (OBD). Hardwired links are also provided to other control modules such as the body processor for cranking information, the security system for engine immobilisation as part of the whole vehicle security package and the air conditioning control module for idle speed control and as an aid

to air conditioning operation. Figure 5 gives an indication of the overall software split within the ECM, this clearly indicates the level of control required for all features but particularly diagnostics.

The ECM consists of two 16 bit Motorola 68HC16 microprocessors each with a memory capacity of 96kB operating with a clock speed of 16MHz. A back up IC communicates with the main processor and can be used to run the engine in a limp home mode in the event of the main processor failing. A power module IC is used as part of the motor drive circuitry for the electronic throttle. High speed communications are processed using a discrete physical layer CAN I/O. A PCB mounted atmospheric pressure sensor is used for fuelling and diagnostic adaptions. The ECM performs signal processing on a variety of inputs, both digital and analogue and contains numerous drivers for the actuators that it controls. The ECM also contains EEPROM memory for non volatile storage (See Figure 6). The ECM is able to perform high speed calculations, high speed analogue to digital conversion and has the capability to handle multiple interrupts.

The first processor controls fuelling, ignition and some diagnostics whilst the second processor controls the throttle and additional diagnostics. Numerous inputs are split between the processors which continually communicate critical information between them to ensure system robustness.

The design requirements for all EMS components and the ECM ensure that correct operation can be maintained in all markets and that component failures do not occur when environmental extremes are encountered. Consequently the inputs to the ECM have been designed to withstand adverse voltages up to 30V yet still operate at voltages as low as 6.5V. Input currents from μA to A are also coped with and each input is monitored to ensure the correct signal occurs during normal operation. The quiescent drain of < 1mA for the system helps ensure that the vehicle meets its overall stand time performance.

The ECM has been designed to operate at ambient temperatures of -30 °C to 85 °C and survive temperatures of -40°C to 100°C. High vibration levels are also withstood and the system is able to survive all electro magnetic compatibility (EMC) immunity tests with field strengths exceeding $75Vm^{-1}$ and pass the radiated emissions tests to the legislative and Jaguar standards within the frequency band 1MHz - 1GHz.

Figure 5: Software Split Within the ECM

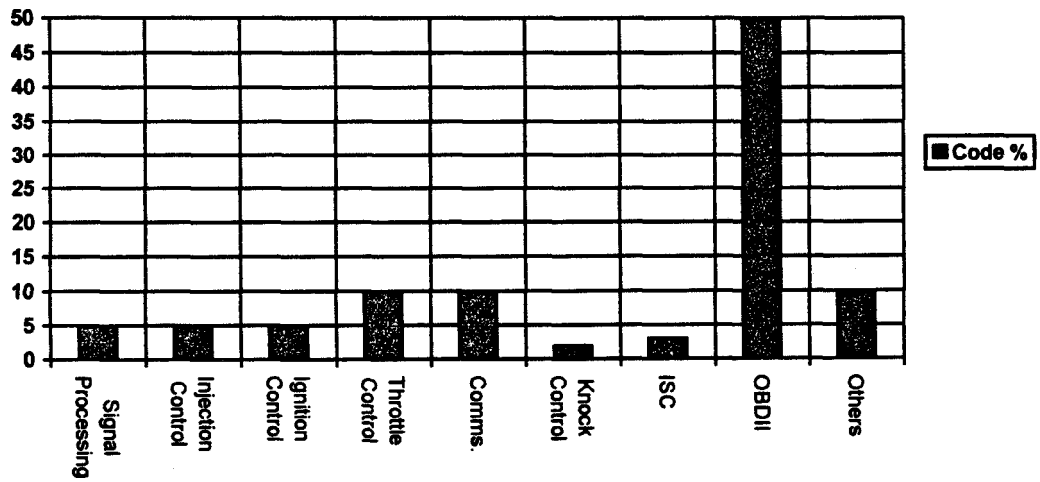
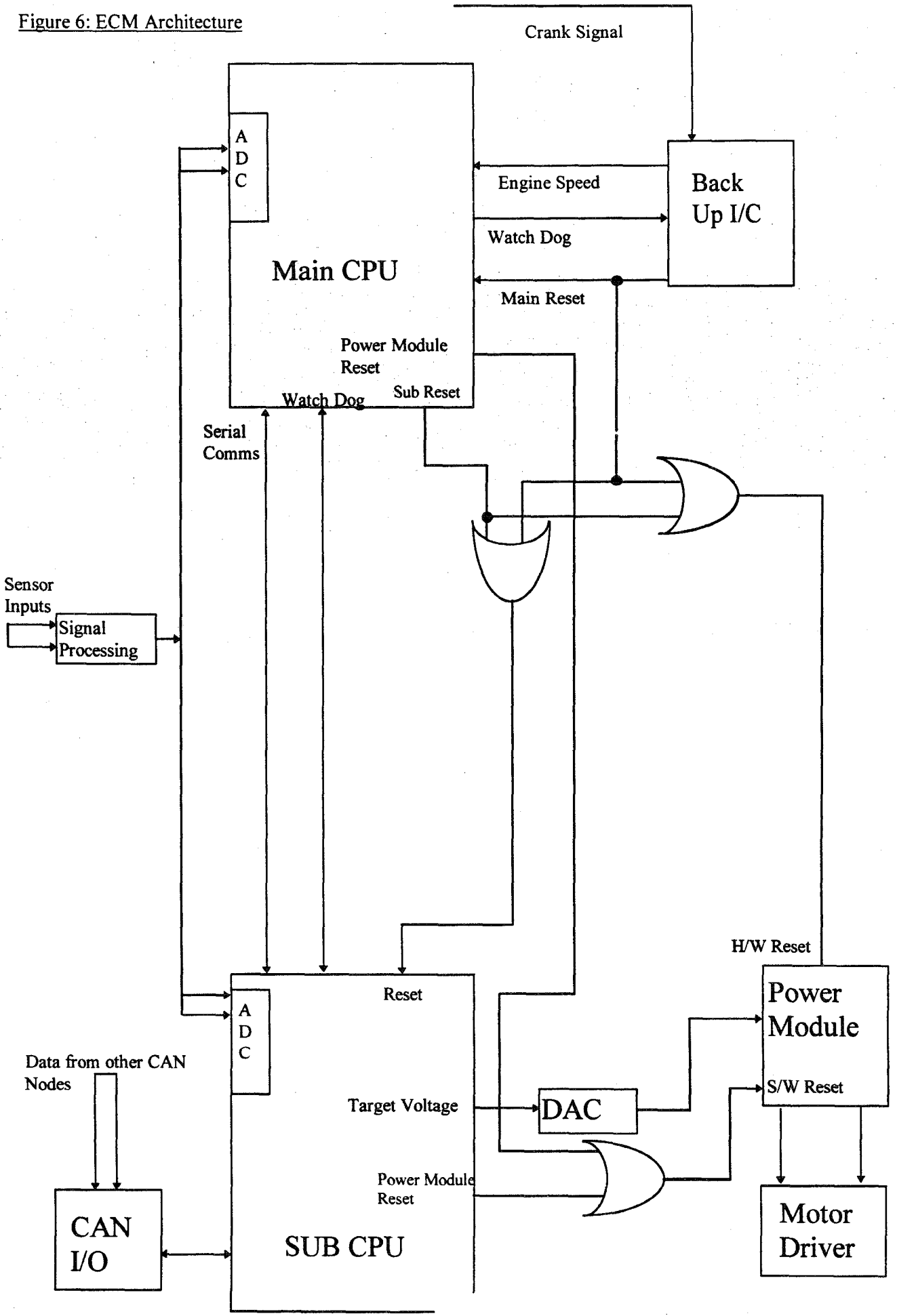


Figure 6: ECM Architecture



2. Throttle Control

The electronic throttle is one of the major innovations of the AJV8 Engine. As on conventional engines it controls the air required for normal engine operating conditions. The AJV8 throttle also automatically governs the air requirement for idle speed control, traction control (reduction of engine power to prevent wheel slip), power limitation (for either gearbox protection or vehicle speed limiting) and cruise control (to maintain the current set vehicle speed).

The overall system design of the electronic throttle includes a mechanical limiter and actuators. This allowed integration of traction control, cruise control, power/torque limitation and idle speed control whilst ensuring that power cannot exceed demand and giving excellent redundancy in the event of any failure.

The throttle has been designed to match or better the performance of current throttle air flow systems typically employing a 4 pole stepper motor. With this in mind the throttle response, resolution, absolute accuracy and air leakage have been designed and developed to meet both the customer and engine requirements.

As well as allowing integration of additional vehicle features the use of electronic throttle control benefits drivability, for example allowing torque converter lock up at lower vehicle speeds and improved tip in/out (dynamic throttle transients) response. Also a more robust starting performance has been achieved since the throttle can be controlled to a known position lower than and independent of the drivers demand.

The mechanical guard effectively leads the throttle blade and also ensures that in the instance of a system fault causing motor shut down the vehicle is still driveable in a mechanical mode as in a normal throttle system.

In normal use the electronically controlled throttle is transparent to the driver and comprises the following components (See Figure 7);

- An input shaft that receives driver inputs from the accelerator pedal via a conventional throttle cable.
- A mechanical guard to prevent the throttle valve position exceeding driver demand and to operate the throttle valve mechanically if the electronic system fails.
- A vacuum actuator to operate the mechanical guard in the cruise control mode of operation.
- A throttle blade to regulate air flow for all engine functions including idle speed control.
- A thermostatic air valve to control a bypass air flow around the throttle valve at very cold temperatures.
- A dc motor to operate the throttle blade via a reduction gear in response to inputs from the ECM.
- Three position sensors comprising
  - Driver Demand: Supplies the ECM with the position of the input shaft. It is a resistive sensor with sufficient outputs to allow system voting.
  - Mechanical Guard: Supplies the ECM with the position of the mechanical guard. It is combined with the driver demand sensors for system voting.
  - Throttle Position: A Hall effect sensor to prevent wear due to throttle dither. It contains integral temperature control circuitry to compensate for drift associated with this sensor type. It is used to determine the throttle valve position.
- Springs connected to the input shaft, the mechanical guard, the throttle valve and the drive gear of the dc motor.

As stated previously electronic throttle control is transparent to the driver. In the normal way the driver will press the accelerator pedal to a required position. The resultant movement via a standard bowden cable moves the input shaft and raises the mechanical guard. The snail cam rotation also rotates a resistive potentiometer which is connected electrically to the ECM. The ECM then drives the DC motor to the required position to achieve the throttle opening that is demanded by that pedal opening. A check is made of the correct throttle position using feedback from the hall effect throttle sensor. (Figure 8)

When cruise control is engaged the ECM calculates the required throttle valve opening and operates the vacuum system connected to the vacuum actuator. The vacuum actuator then turns the mechanical guard to a position that allows the required throttle opening. The inputs from their respective position sensors allow the ECM to monitor and adjust the mechanical guard and throttle blade to maintain the set speed. As the driver releases the accelerator pedal the input shaft disengages from the mechanical guard.

To prevent wheel slip as part of the traction and stability control mechanisms the ECM is able to reduce engine torque by retarding the ignition, inhibiting fuel injection or by closing the throttle. Fast response is provided by ignition retard followed by inhibiting fuel injection and closing the throttle which is capable of achieving a much greater reduction in engine torque if required.

The engine control module uses a voting system on the driver demand inputs to determine the actual driver demand required, therefore even under certain failure conditions normal vehicle operation can be maintained with only a driver warning given. Diagnostics take place to ensure system robustness, driver safety and to ensure that the driver and certification authorities are informed of a failure that will increase the vehicle emissions level.

Figure 7: Electronic Throttle Assembly

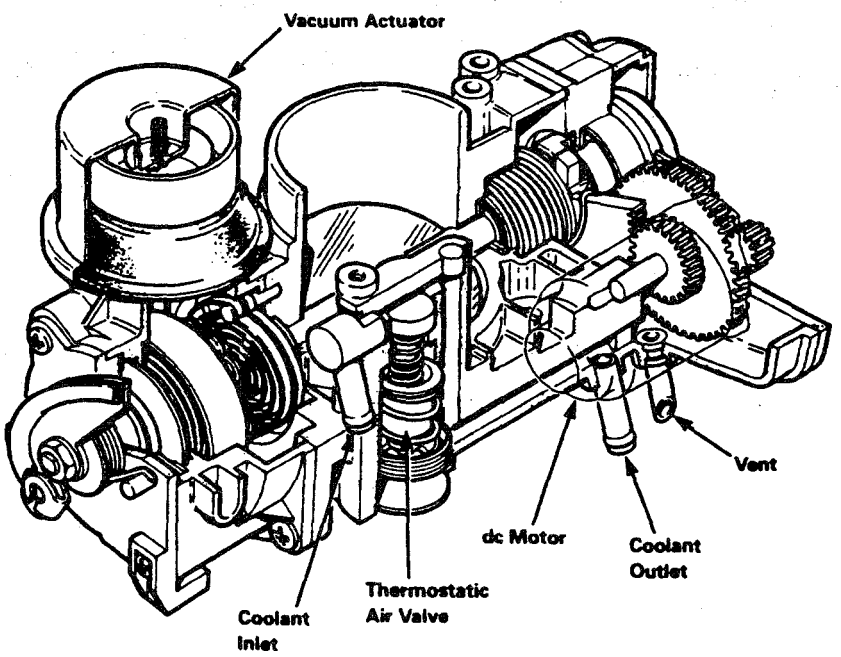
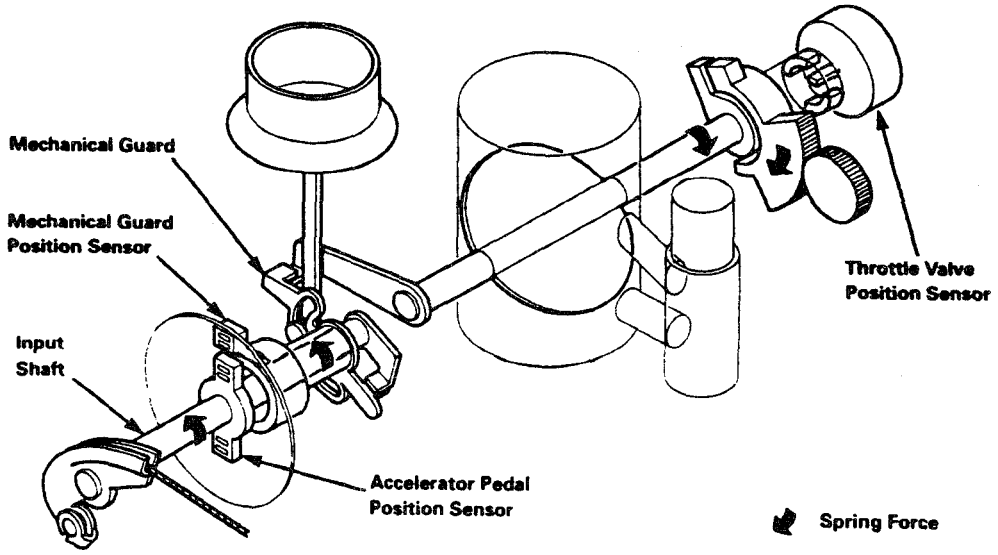


Figure 8: Simplified View of Electronic Throttle



3. Ignition Control

Correct timing is one of the primary requirements for accurate ignition and fuelling control. The ECM timing information comes from 2 sensors as follows:

Primary engine speed sensing is determined from a variable reluctance sensor mounted on the flywheel. The timing disc, sensor, mounting and air gap have all been designed such that accurate engine speed information is available at all engine speeds from 30rpm to over 7000 rpm.

The engine position is determined by a variable reluctance sensor mounted on the camshaft of B bank with a signal generated once every 2 engine revolutions.

The ECM varies the ignition timing to optimise power, emissions and driveability at all engine operating conditions. The ECM controls ignition timing and spark energy via 2 ignition amplifiers and 8 on-plug coils. The ECM triggers the ignition amplifiers which in turn control the flow of current in the coil primary circuit of the on plug coil. The high tension voltage from the coil is created when the primary current is switched off.

The ignition amplifiers have been designed with their own integral hardware diagnostics to enable the ECM to determine if a correct fire of the relevant coil has occurred. Should a failure be detected the ECM disables fuel injection to the affected cylinder preventing unburnt fuel passing through the engine and damaging the expensive exhaust catalyst system.

On plug ignition coils are used to deliver the spark energy to each spark plug. The use of on plug coils has numerous advantages for the electrical and mechanical design of the engine and vehicle.

- *Reduces electromagnetic interference since no open sparks occur*
- *No rotating components*
- *No high tension leads required*
- *Noise reduction*
- *Improves the packaging space available*

Compensations to the ignition timing are made when inputs from the temperature sensors, traction control, transmission controller, knock sensors, Exhaust Gas Recirculation (EGR) flow, fuel cut off (high engine speed with a closed throttle usually referred to as overrun), full load advance and the camshaft position (VVT) determine that this is required.

3.1 Variable Valve Timing

The variable valve timing system improves low and high speed engine performance, engine idle quality and exhaust emissions by altering the basic thermodynamic cycle of the engine. It is a two position system that operates on the intake camshafts only. There is 30° of crankshaft movement between the retarded and advanced positions. Engine oil pressure is used to operate the system to the advanced position under the control of the ECM via two valve timing solenoids (1 per bank), whilst return springs move the camshafts to the retarded position.

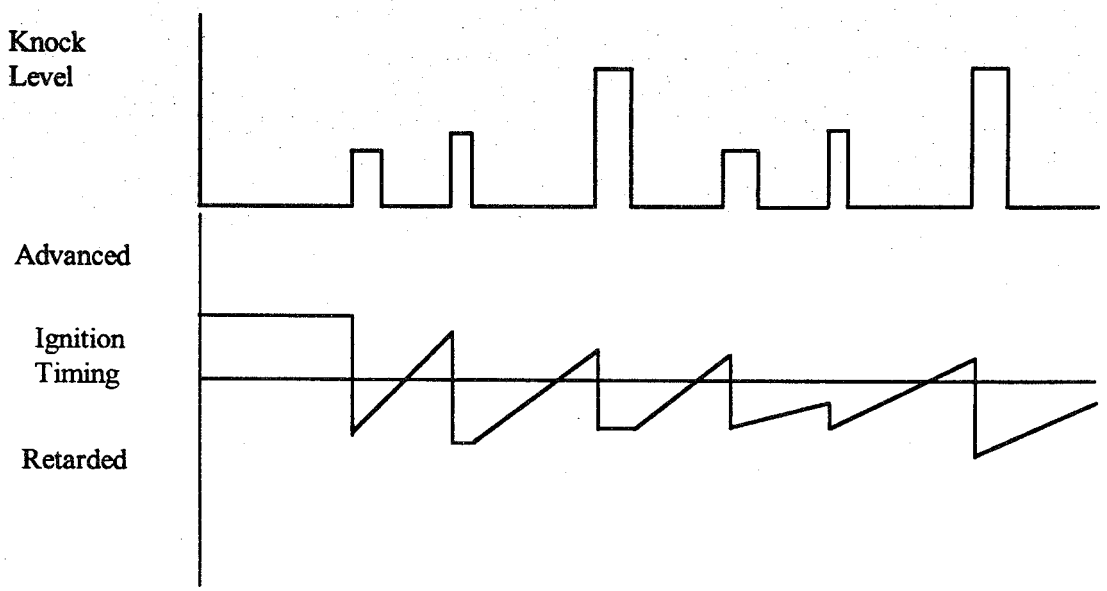
3.2 Transmission Interface

In order to reduce any shock associated with a gearshift the engine torque is momentarily reduced by retarding the ignition simultaneously with a gearshift. The request for torque reduction is communicated by the transmission control module via CAN.

3.3 Knock (Detonation) Control

Engine ignition is normally performed close to the detonation limit in order to improve fuel economy and increase power output. Knock sensing allows calibration of the ignition timing for normal operating conditions with the risk of detonation eliminated by the use of knock control. Two accelerometers (knock sensors) (1 per bank) mounted on the engine block are used to determine the onset of detonation by sensing engine vibrations. The sensors output signals to the ECM, which ascertains which cylinder has detonation present and retards the ignition timing on the affected cylinder to prevent this. The reference level (background noise) for the knock detection is calculated from the average value of sensor signal when detonation is not taking place.

Figure 9: The effect of knock detection on ignition timing



4. Fuelling Control

The ECM operates eight twin jet bottom feed fuel injectors to provide the engine with fuel. The amount of fuel required is determined from a base air fuel ratio map, based on inputs from the engine speed sensor and the hot wire mass air flow meter (The map is a look up table with the axis as described, individual points are referred to as sites). The base air fuel ratio is then adjusted for specific operating conditions. Additionally the ECM also controls the fuel pump via a relay.

The ECM varies the number and duration of the injector pulses per engine cycle to regulate the fuel flow. Feedback signals from oxygen sensors in the vehicles exhaust system enable the ECM to exercise closed loop control of the fuelling, except during full load enrichment when the injector pulse width is increased to maintain a stable exhaust system temperature.

Adaptive fuelling accommodates engine efficiency variations, system tolerances and engine ageing. Adaptions occur at several sites throughout the speed and load range.

Fuel flow through the injectors changes with voltage, so the ECM monitors their supply voltage and compensates for any variation from the normal.

5. Diagnostics

The increased complexity within the EMS required a more sophisticated diagnostic system with strategies to complement the overall design.

The diagnostic system within the ECM detects abnormalities in the sensors, actuators and vehicle harnesses. When a failure is detected the ECM automatically stores relevant system information to assist the technician in performing a repair on the vehicle. The ECM will also adopt alternative values and assume a 'limp home' condition. The decision on limp home values and strategies is particularly important since electrical failures usually result in a catastrophic failure where as mechanical failures lead to a degradation failure.

The design and development of the diagnostic strategies formed an integrated part of the overall EMS design and has reduced service and repair times to the benefit of both the customer and vehicle dealer.

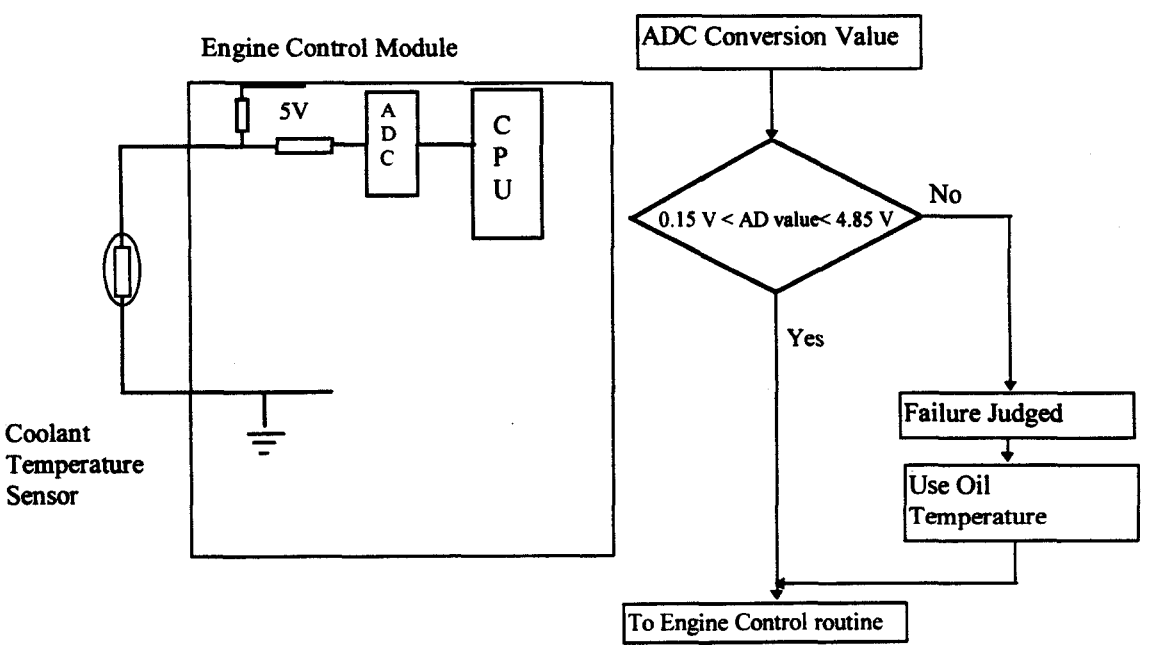
5.1 Diagnosis Method

The increased complexity in the EMS required the diagnostics to be designed to form an integrated part of the overall system design. Without on-board diagnostics it would be impossible for any technician to quickly and accurately diagnose and repair any but the most simple failures. Diagnostics and failure detection is possible by the ECM in around 150ms and on detecting a failure, accurate information is stored on the failure type together with freeze frame data (e.g. engine speed, engine load, coolant temperature, vehicle speed) at the time of the failure.

A number of diagnostic strategies can be applied to the EMS sensors and actuators. The decision on the type of failure diagnosis was made by evaluating the customer, vehicle and legislative requirements.

Sensor open and short circuit failure diagnosis is performed by analysing the inputs from the sensors and judging them against known correct values. The known correct value is determined through theoretical analysis and practical testing. Consideration is given to a number of factors, and these include ambient temperature, atmospheric pressure (and hence altitude), time after start and air flows. A failure is judged when the signal from the sensor is outside the range that is conceivable compared against expected engine and vehicle operating conditions. See Figure 10

Figure 10: Sensor circuit failure detection



Additional sensor faults also diagnosed include 'stuck at' faults where for example the air temperature sensor resistance could stick giving a constant temperature reading of 100°C. These type of faults would not be diagnosed using the above method since the output voltage would fall inside the normal voltage range.

In determining the method of detecting this type of failure the following techniques were considered. The use of additional sensors would allow accurate determination of a failure. However, three sensors would be required for a rationality check and this would mean additional costs for sensors, ECM hardware inputs and harnessing. The vehicle package would also be compromised. A better solution was engineered whereby the sensor to be checked was referenced against a model with inputs from other EMS sensors. For example to detect a stuck inlet air temperature sensor;

1. Is the air temperature = 100 °C (Still within range)
2. Is the coolant temperature < 40°C
3. Is the engine speed > 2000 rpm
4. Is the vehicle speed > 50 kph

Since it is not possible for all four to be true then the appropriate failure judgement will be recorded.

In determining failures of this type experiments were conducted which examined the influence factors for the diagnostic. These factors were then adjusted either in software or by building special hardware to determine what the worse case result could be. These results were then used in software and hardware that ran in durability vehicles at the environmental extremes. Special monitoring equipment was added to these vehicles that recorded the diagnostic result when both pass and failure judgements were recorded. In this way it was possible to determine how much headroom was available between the pass and failure judgement and hence the risk to the programme for false detection. The results were analysed and changes made to either the diagnostic strategy or the vehicle hardware to increase the diagnostic headroom.

An actuator failure is diagnosed by adding a monitor circuit to the ECMs actuator circuit. See Figure 11. The control signal is checked against the comparator voltage, when a difference is encountered a failure judgement can be made, usually after a counter has exceeded a set time to prevent false detection (See Figure 12).

Figure 11: The addition of a monitor circuit for actuator failure diagnosis

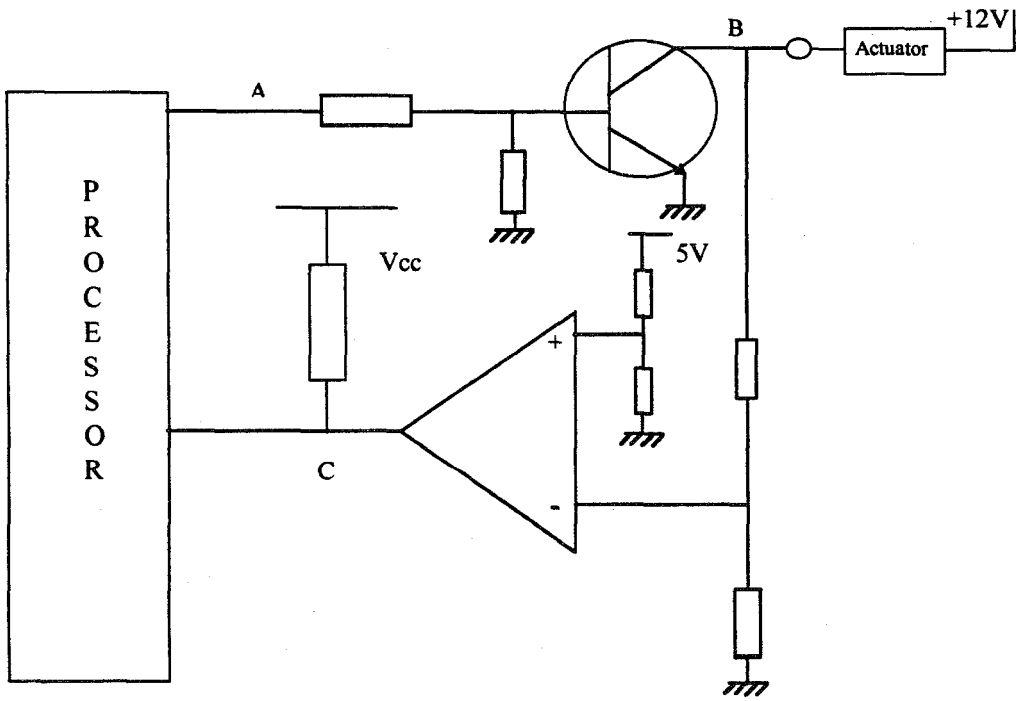
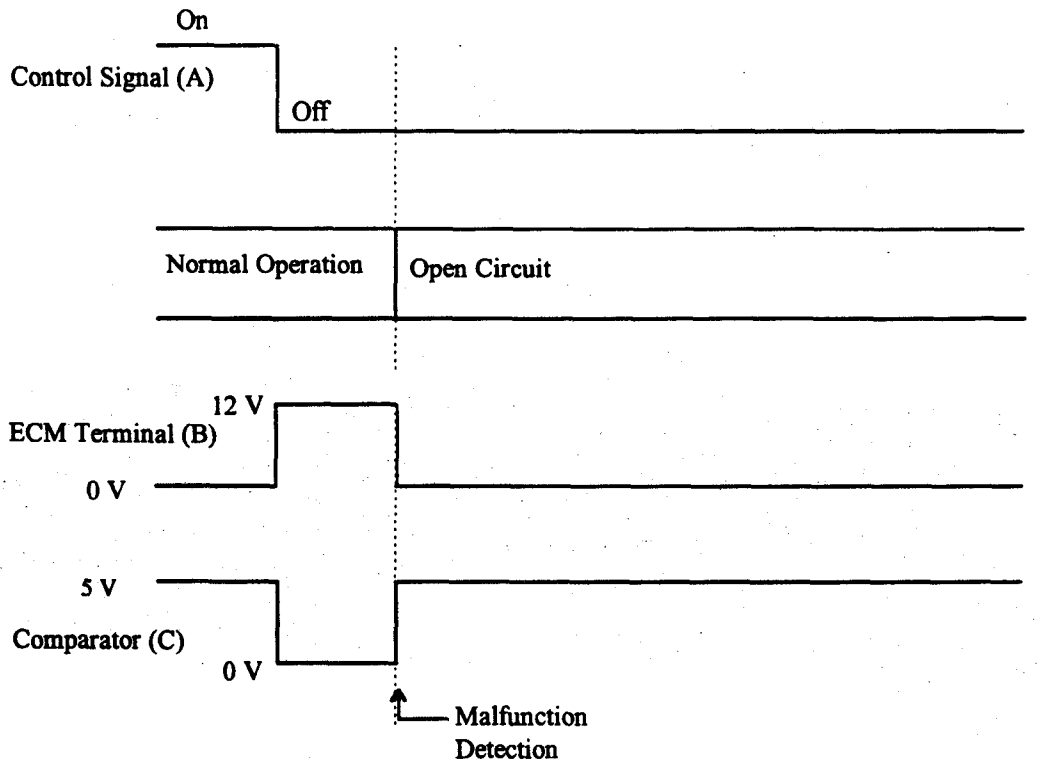


Figure 12: Timing chart for actuator failure diagnosis



Summary

High reliability is essential in modern vehicles and is now (and has been for some time) considered normal by customers. All vehicle components must be capable of correct performance in the harshest of environments but this is particularly true of the EMS given the catastrophic failures that could occur. With this in mind the overall design of the Engine Management System provides highly competitive performance, refinement and fuel economy whilst complying with the most stringent world-wide emission legislation requirements. This assures customer satisfaction and legislative compliance in all markets. The comprehensive diagnostic strategies guarantee ease of service, enhance production quality and prevent excess emissions. The design and use of electronic throttle control improves drivability and allows full system integration, yet gives full mechanical back up in the event of any failure. Communications with other nodes via CAN enable robust transmission of data between all control modules.

Acknowledgements

The author would like to thank the support of his colleagues and the Denso corporation for their involvement in the writing of this paper and in the design of the AJV8 EMS.

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THE SAFETY ASSURANCE OF THE AJV8 ELECTRONIC THROTTLE

Ian Kendall MA (Cantab) MSc CEng MIEE

Electrical Engineering, Jaguar Cars Ltd.

ABSTRACT

Electronic throttle is a major innovation of the AJV8 engine in the XK8 vehicle. Although essentially transparent to the driver, it moves Jaguar into new territory, and has often been referred to in the past as "drive-by-wire". Jaguar, in partnership with the Denso Corporation, has developed a system that, while still offering a simple mechanical solution to assuring overall safety, also recognises the importance of the increased criticality placed on computer controls. This paper will discuss both the system safety concepts, and describe the state-of the-art methods that have been used throughout the development of the XK8.

INTRODUCTION

The all new Jaguar AJV8 engine, which powers the XK8, has many new advanced features. Electronic throttle is the application of computer control to replace the traditional mechanical throttle cable, enabling the engine power to by determined electronically, based on sensors that measure driver demand. Hence the term "drive-by-wire".

Generally speaking, computers used to control anything can give rise to two extreme opinions. At one extreme is the view that computers are infallible, and offer vastly superior functionality and intelligence in the way a system behaves - the "technophile's view". The opposing view is that computers are unreliable, and very difficult to diagnose when they go wrong - the "technophobe's view". Which view you take depends on a) what experiences you have had with computers, and b) how much you know about designing computer control systems. When computer control has safety implications, these views can become sharply polarised.

The reality is that computers can, and do, offer greatly enhanced functionality, reliability and safety to many products in everyday use - provided they are designed to do so. This paper offers an insight into the techniques used to provide Jaguar XK8 customers with all the features and performance associated with a computer controlled throttle, while maintaining the very high standard of safety which they are entitled to expect.

Safety can be thought of as an aspect of quality. It has been suggested that if quality is defined as "fitness for purpose" and "meeting the needs of a customer" then a high level of quality also implies a high level of safety. The XK8 electronic throttle therefore needs to exhibit high quality and safety to meet the targets set for the programme. In achieving this, we have relied on several new approaches, along with many tried and tested ones, and subjected everything to independent assessment and audit by Lloyds Register, who are one of the leading safety assurance organisations.

This paper describes the design of the electronic throttle system, the safety features it includes, and the engineering process used to assure the safety and quality.

THE ELECTRONIC THROTTLE SYSTEM DESIGN FOR AJV8

The electronic throttle is an integral part of the engine management system, and is supplied to Jaguar by Denso Corp. according to Jaguar specifications. In the early stages of the project, Jaguar sought the advice of Denso Corp. on how to tackle the issue of safety on such a system. They offered the approach of "evolution" rather than "revolution", which allowed the system to be designed such that that it offers

the benefits associated with electronic throttle, while maintaining the safety characteristics of a conventional mechanical throttle. This is achieved by ensuring the electronics do not have full authority over the movement of the throttle valve blade. The mechanical parts, which are based entirely on current, well understood and accepted designs, provide a physical protection barrier and a limp-home facility. The effect of this is that the electronics cannot give rise to a throttle position far above that which the driver intends.

The electronic part of the system features sensors to measure the driver's demand using the accelerator pedal position; sensors to determine the actual position of the throttle valve blade; an electrical motor which drives the throttle valve blade via a reduction gear; and electronics which are part of the Engine Control Module (ECM). The mechanical components consist of a conventional cable linking the accelerator pedal to the throttle body on the engine, a "mechanical guard", a diaphragm vacuum actuator and associated switching valves and vacuum tank, and several springs. (See Figure 1).

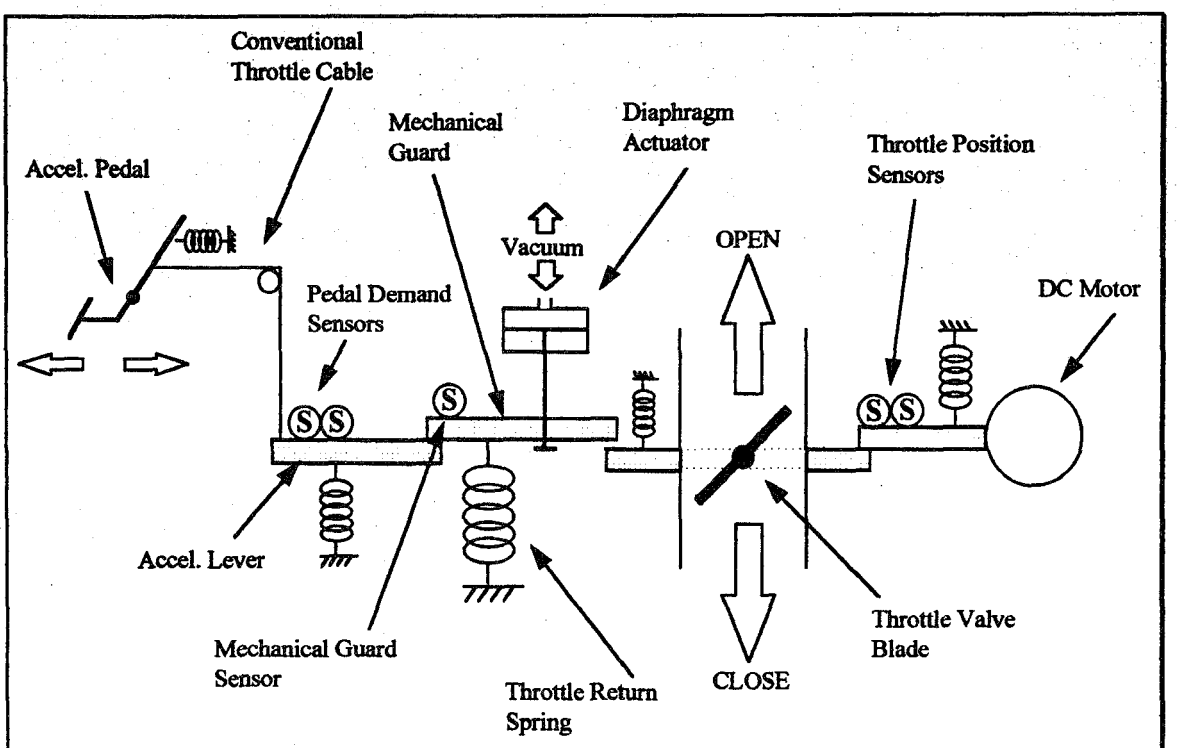

Figure 1 - AJV8 Electronic Throttle Body - Main Components

THE MECHANICAL GUARD

One of the most significant aspects of the electronic throttle design for AJV8 is that it does not seek to replace the mechanical throttle cable, but rather supplements it. The accelerator pedal under the driver's foot is still connected to a cable, and that cable still transfers the physical motion to the throttle body on the engine itself - all totally conventional. However, the motion of the cable does not act directly on the throttle valve blade, it acts on a device we call the mechanical guard. The throttle valve blade, which regulates the amount of air going into the engine, and hence its power output, is actually controlled below the mechanical guard position by an electrical motor. In essence the mechanical guard puts a physical barrier in place, such that the authority of the electronic control is always less than that allowed by the mechanical range. If the driver takes his foot off the pedal, the mechanical guard will close in the same way as a conventional throttle, and except in cruise control (see later), it will always override the electrical motor (i.e. the mechanical guard spring force > the throttle spring force). The mechanical guard therefore plays an essential role in assuring safety by limiting the authority of the

electronic/computer controlled elements, behaving in an obvious and predicable way as in any conventional throttle system.
The mechanical guard, of course, is subject to failure modes the same as any other mechanical component (breaking, jamming, etc.), but these can be predictably analysed for their effects, and monitoring functions provided by the computer can warn the driver before safety is affected. Hence this provides an enhancement of the safety performance of system through the functionality made possible by the electronic control system.

THE CRUISE CONTROL SYSTEM

When the driver selects the cruise control function, the system maintains the vehicle speed at what ever it was at the instant the "SET" button is pressed. The driver can then increase or decrease this using the "ACCEL/INCH-UP" and "DECEL/INCH-DOWN" buttons. The function is usually cancelled by slightly depressing the brake pedal, although there are many other ways in which control can be returned to the driver. Once cancelled, if the "RESUME" button is pressed, the vehicle will return smoothly to whatever the set speed was before it was cancelled.

The cruise function is realised by the electronic throttle, however we have said that the opening of the throttle valve blade is constrained by the mechanical guard. In most circumstances in cruise control, the driver will have his foot off the accelerator pedal, and hence the guard will be closed. This situation is handled by the diaphragm actuator, which uses the inherent vacuum available on the engine inlet manifold to withdraw the mechanical guard, via a series of valves under the control of the ECM. The safety integrity of the electronic throttle in cruise control, is thus a special case. The mechanical guard is not fully opened, but only as far as is required according to the throttle position needed to maintain speed (e.g. it will open more when going up hill, as the throttle must open to provide more engine power). In addition, there are several features that ensure that if the driver cancels the cruise function, the vacuum will be released, allowing the mechanical guard to close. This is achieved with redundant Vacuum Switching Valves, or VSV's, one of which is operated via the ECM control software, the other is directly switched electrical via the brake switch circuit. The circuits and valves are configured such that they always fail safe, i.e. always releasing the vacuum, closing the mechanical guard. (See Figure 2).

FAIL-SAFE DESIGN AND REDUNDANT ARCHITECTURE

The whole electronic throttle is designed such that it always fails safe. This requires that critical components should be supported by redundancy. Redundancy enables the detection of malfunction in one component using the other, and increases system availability. In the case of sensors, it is possible to use one sensor to check the reading from the other (e.g. dual throttle position sensors), or to "vote" the majority if there are more than 2 (e.g. dual driver demand sensors plus the mechanical guard sensor). In some cases it is possible to estimate a value from other related sensor data. For actuators, redundancy can provide back-up that can be used in the event of the primary component failing (e.g. the DC motor and Mechanical Guard/Throttle Return Spring) or be combined such that either or both must operate to produce the required action. In North America, regulations require that there shall be two means of returning the throttle to idle. The XK8 complies with this by considering the Mechanical Guard and Throttle Return Spring as one means, and the DC motor as the other, as both mechanisms can close the throttle even when the other has failed.

The Electronic Control Module (ECM), which contains two 16-bit microprocessors. The throttle is controlled by only one of the processors (actually called the Sub CPU), but the other (the Main CPU,

so called because it manages fuelling and ignition) contains diverse software that monitors the throttle function calculation in the Sub CPU for malfunction.
Other examples of redundancy are:

- Dual circuits within the wiring harness for the DC Motor connections and sensor power and ground connections,
- The power to the DC motor can be cut by switching off the power drive circuit in the ECM or by an external relay,
- Return springs on both the accelerator pedal and the throttle body,
- Dual brake pedal switches, one normally open, one normally closed,
- A total of 31 separate means of cancelling cruise control,
- Two valves that can independently release the vacuum on the diaphragm actuator.

The question that needs to be answered is how can we be sure that we have done everything practical to ensure a safe system. To answer this we need to explore the safety engineering process and how this was supported by Lloyd's Register, who were contracted to oversee and support the design and development activities, both at Jaguar and Denso Corp.

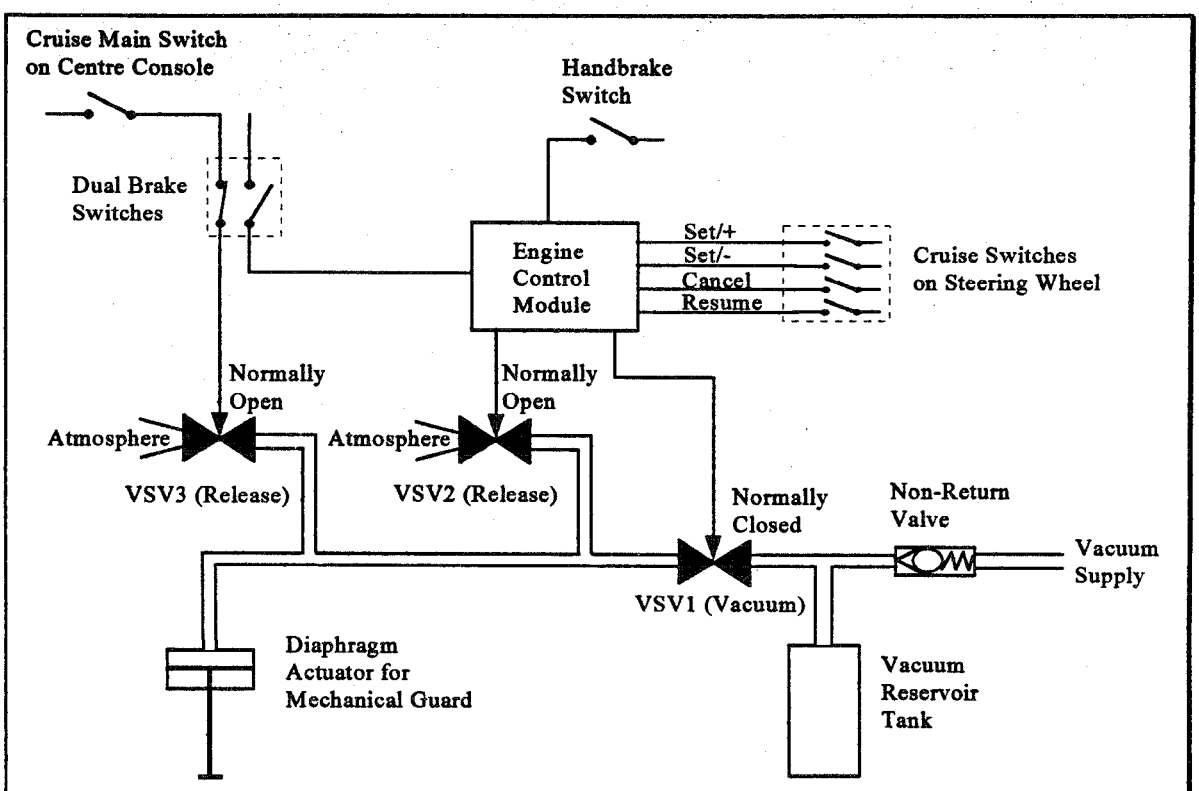

Figure 2 - Cruise Control System - Main Components

THE SAFETY ENGINEERING PROCESS USED ON THE XK8

Around the time work started on the AJV8 engine, the International Electronic Technical Commission published a draft standard on the subject of "Functional Safety", now called IEC 1508 [Ref 1]. It is also noteworthy that, in the UK, the motor industry formed a research consortium (MISRA) which, with DTI funding, published "Guidelines for the development of vehicle based software" [Ref 2]. This focused strongly on safety-related design within the automotive sector. Jaguar was a key member of this group and was keen to use many of the MISRA ideas at the earliest opportunity. Jaguar sought Lloyd's

Register's advice on how to address these emerging standards issues to ensure a state-of-the-art approach on AJV8 [Ref 3]. The remainder of this paper describes the work that has been done to achieve this.

THE SAFETY OBJECTIVES/SAFETY MISSION

In the early stages of the project, Jaguar defined the specific safety objectives for the system. These we based on IEC 1508 that identifies 4 classes of risk, which are known as: Class I (Intolerable), Class II (Undesirable), Class III (Tolerable) and Class IV (Negligible). Class I therefore represents the highest, intolerable, risk, and Class IV represents the lowest possible risk. The concept of a risk-based approach uses the principle that risk is a combination of how serious an event is, and the chances of it happening, i.e. RISK = SEVERITY OF CONSEQUENCES x PROBABILITY OF OCCURRENCE.

The main mission was to design the electronic throttle such that it only had a risk class of IV, i.e. negligible. In order to demonstrate this we had 3 main objectives:

- There shall be no hazardous single point failure modes.
- The likelihood of there being any multiple-point hazardous failure modes, shall be shown to be in accordance with risk class IV (Negligible).
- Any safety-related software is developed to an appropriate standard (appropriate process).

Lloyds Register's role was to assist us in achieving these objectives.

PRELIMINARY HAZARD ANALYSIS

One of the most important safety engineering activities is to identify the potential consequences associated with the failure modes of the system, and to categorise them according to their importance. This is often called Preliminary Hazard Analysis. In IEC 1508, a "hazard" is defined as "a situation with potential for human harm". Our first task to work together with Lloyd's Register and Denso Corp. to list all the situations we could think of which would allow the electronic throttle system to generate a hazard. Each of these was categorised according to the MISRA severity scale [Ref 2] as follows:

- **Uncontrollable**. Failures whose effects are not controllable by the driver. The outcome cannot be influenced by a human response.
- **Difficult-to-control**. Failures whose effects are not normally controllable by the vehicle occupant but could, under favourable circumstances, by influenced by a mature human response.
- **Debilitating**. Failures whose effects are usually controllable by a sensible human response.
- **Distracting**. Failures which produce operational limitations, but a normal human response will limit the outcome.
- **Nuisance**. Failures where safety is not normally considered to be affected.

REVIEW OF INTERNAL STANDARDS AND PROCEDURES

Lloyd's Register were asked to review the design standards, component test specifications, vehicle test specifications, and management procedures at Jaguar and Denso Corp. and to concur that they were suitable for the electronic throttle system. It was concluded that they were in line with the emerging standards and practices in other industry sectors such as defence, and aerospace, which have been tackling complex, safety-related control systems for many years.

AUDITS OF SOFTWARE DEVELOPMENT PROCESS

Lloyd's Register made several visits to Japan to audit Denso Corp. against their software development process to ensure that they were following it. They used "TickIT" methods [Ref 4], which support ISO 9000-3 (specifically for software), however the intention was not to certificate Denso Corp., but to ensure that the software development process was appropriate for this project. This a very important activity as it is well accepted that software cannot to shown to be suitable for is intended use by testing alone, as the number of test configuration combinations which even simple software exhibits becomes very large indeed. Software robustness must be demonstrated by ensuring the process used to develop it is appropriate, and that this process is rigorously followed. This work has proved extremely valuable in ensuring we have the necessary confidence in the software. However, it must be remembered that the software criticality is reduced by the presence of the mechanical guard, which ensures that, if it malfunctions, the throttle opening is restricted to only slightly above the driver's demand on the accelerator pedal.

FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

This technique has been established practice in the automotive industry for many years. The technique is to consider each component in the system, analyse each of its individual failure modes, identify the possible causes, attempt to predict the effect, and recommend design improvement and development action to avoid problems before they happen [Ref 5]. FMEA's can be performed at several different levels of detail. For the electronic throttle system, several FMEA's were performed independently throughout the programme by Denso Corp., by Jaguar and by Lloyd's Register. At Jaguar the analysis is extended to "Failure Mode, Effect and CRITICALITY Analysis" (FMECA). The result of the FMEA's was to demonstrate successfully the safety objective that there shall be no single-points of failure leading to a hazardous state.

FAULT TREE ANALYSIS (FTA)

FTA is inverse of, and is used to complement, FMEA [Ref 6]. Instead of starting with single-point failure modes and working towards the effect, here the starting point is the effect, which for safety analysis is the hazard, and then work down towards all the possible causes. This captures combinations of faults that can lead to a hazard, otherwise known as multiple-point failure modes, as well as confirming that there are no single-point failures. Fault trees were constructed both by Jaguar in the early stages of the project, and later independently by Lloyd's Register, to show that the combinations of faults that had to occur before a hazard arises were highly unlikely. By refining the fault tree analysis down to component failures, we could estimate the probability of a hazard.

MARKOV MODELLING

This was performed by Lloyd's Register as an alternative to the quantified fault tree produced by Jaguar. A Markov model breaks the system into states, the most relevant ones being the "normal" state and the "failed" state, and assigns a probability for moving between states based on the likely reasons for doing so [Ref 5]. The net result is that this technique can also produce an estimate of the probability of a hazard occurring over the design lifetime of the vehicle. Both Jaguar's quantified FTA and Lloyd's Register's Markov Model are used to demonstrate the second safety objective, i.e. that the probability of a hazard was in accordance with risk Class IV (Negligible).

SOFTWARE DOCUMENTATION REVIEW

The software is written by Denso Corp., to Jaguar's specification. Lloyd's Register were asked to review this specification, and the documentation generated by Denso Corp. for both the software requirements and design. The main result was to identify those areas within the software relating to safety, ignoring the fact other system components in the overall design such mechanical guard, provide a higher level of protection. It was also possible to examine these areas of the software in more detail and formulate "Safety Properties" in relation to the hazard analysis mentioned earlier.

PROOF OF SOFTWARE SAFETY PROPERTIES

The safety properties of the software were initially identified in descriptive English text. The word "proof" implies some form of mathematical manipulation that asserts a true fact. Hence, it is first necessary to translate the safety property statements into a mathematical representation that lends itself to manipulation, and secondly to relate this to the software code. This is a highly specialised task, and again we relied on Lloyd's Register's expertise to perform it. They were able to mathematically manipulate of the resulting equations to show whether a property was fulfilled or not. At first, in some instances, a property could not be shown to hold in all conditions, but by reviewing these in detail with Jaguar and Denso Corp. experts on throttle control and vehicle design, it was possible to show that the "exceptions" were all valid conditions that were entirely consistent with design intention.

SAFETY VALIDATION TESTING

Jaguar is responsible for ensuring that the XK8 vehicle meets all the requirements of its test specifications, which in turn are aimed at reflecting customer usage patterns. Throughout the entire programme, even on the first prototypes there is validation. Cars are taken out to Timmins in northern Canada in the winter to do "Cold Environmental Tests", where the temperature is well below -30°C, and to the Arizona desert for "Hot Environmental Tests" where is often exceeds +50°C. We do whole vehicle Electro-Magnetic Compatibility (EMC) test to meet very strict standards as well as all international regulations. We have many tests for durability, driveability, vibration, thermal shock, resistance to fluids, etc. etc. All of this ensures that when the vehicle is signed-off for production, we have been as exhaustive as possible. The electronic throttle gets subjected to all of these vehicle test conditions as it is an integral part of the car. However, we also identified the need to perform specific safety validation tests. The difference is that the majority of the "standard" validation suite considers only normal operation, safety validation must consider the effect of the vehicle under as many failure conditions as is possible to generate. For single points of failure, we aimed to show that each failure would cause the vehicle correctly to enter one of the seven possible default modes. These are:

- Redundancy Mode - no effect at all, driver warning only.
- Cruise Control Inhibited Mode - cruise control function cancelled and disabled.
- Mechanical Guard Mode - Throttle deactivated completely, runs using mechanical guard, and with "fuel intervention" that partially cuts fuel to individual cylinders.
- Full Authority Mode - Mechanical guard failed, throttle still active but with a vehicle speed limit to reflect the loss of safety margin.
- Gearbox Protect Mode - Throttle opening limited to 30 degrees, for gearbox failure and in reverse gear.
- Fixed Idle Mode - Throttle closed to give a "high" engine idle.
- Engine Shutdown Mode - Engine cuts out by stopping fuelling completely.

Jaguar also checked that the correct warning was given to the driver on the instrument cluster, which include "Check Engine", "General Red" and "General Amber" warning lights, together with a text message on the LCD display.

For the multiple failure modes, combinations of the faults were considered. For two point failures this was achieved by combinations of the seven main default modes. Some three-point failures and one four-point failure were also checked.
Lloyd's Register were invited to witness some of the test work, the majority of which was carried out at the MIRA Proving Ground, where each failure situation could be safely evaluated. It was shown that the testing was suitable for its intended purpose in demonstrating the overall safety of the electronic throttle at the vehicle level.

SUMMARY

The aim was to ensure that the electronic throttle on the AJV8 engine in the XK8 has been engineered to a standard of excellence befitting such a feature on a passenger car. We believe that state-of-the-art engineering methods were used to design, analyse, test and assure the system. The main facts to support this claim are:

- Highly capable, world-class quality supplier.
- Robust, high reliability mechanical design, which "guards" the authority of the control system and provides limp-home facility.
- Application of safety engineering techniques, following emerging standards such as IEC 1508 and the MISRA Guidelines.
- Extensive third party expert independent technical assessment and audit.
- Identification and management of potential hazards and technical risks throughout the development.
- The setting of safety targets and ensuring they are met.

The evolutionary design facilitated by the mechanical guard has resulted in a final product that has all the benefits of advanced computer controls, while maintaining the high level of safety and predictability of conventional mechanical throttle actuation.

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THE XK8 HIGH SPEED POWERTRAIN SERIAL COMMUNICATIONS SYSTEM

By

Andrew Croft BSc, MSc, CEng. MIEE

Electrical Engineering, Jaguar Cars Ltd

ABSTRACT

Serial Communications within vehicles has emerged as the enabling technology for the next generation of electrical vehicle architecture. Currently, many of the major automotive companies are evaluating serial communications as a solution for delivering real-time control powertrain system functions. Amongst the front runners is Jaguar.

This paper highlights how Jaguar has successfully implemented high speed serial communications technology, Controller Area Network (CAN), to enable communications between powertrain sub-systems entailing Anti-Lock Braking System (ABS), Engine Control Module (ECM), Transmission Control Module (TCM) and Instrument Pack. This high speed network is the core of the vehicle electrical system which enables enhanced feature and refinement of vehicle functions and service bay diagnostics, allowing the XK8 to meet all current emissions legislation, whilst maintaining best in class drivability.

1. INTRODUCTION

The vehicle of today is no longer perceived by customers solely as a means of getting from A to B. Modern customers pay particular attention to a vehicle having the right feature at the right price and of the right quality.

As customer demands have increased, the complexity of the vehicle electrical system has mushroomed to such a degree that practically every feature within the vehicle has become dependent upon some form of electrical interface. Technology is now perceived as a competitive weapon due to its ability to increase feature level, and applications achieved via the use of technology in the luxury market undoubtedly provide a competitive edge, which is a critical factor in any business environment, since a company's success is likely to depend upon it.

In order to remain competitive within the luxury car market it is the responsibility of engineers to find ways of achieving the upwards pressure on functionality for the customer, at higher quality and with more reliability while at the same time handling the downward pressure on cost, weight and time to market.

2. A TECHNICAL OVERVIEW OF CAN SERIAL COMMUNICATIONS

Powertrain and chassis control place demands on a vehicle's electronic systems. These systems/modules must be able to handle the rapid responses that are necessary to make them perform properly in a real-time environment.

Serial communications enables this process as it provides a means for the interchange of inter-module data and control information at high speeds on a single bus. Its role is to ensure that any communication between these systems is fast enough to cope with the demands made upon them.

Serial communications is the technique by which many functions, normally carried by numerous wires, is passed along a single medium - a twisted wire pair in Jaguar's case. The information is converted to digital form (i.e data) and transmitted as a series of binary digits, 0 and 1, along the twisted wire pair. The speed at which the numbers can be transmitted allows the sequential nature of the information to be hidden i.e the faster the better. The numbers are coded by allocating voltage pulses to time slots and using the pulses to represent the binary digits, 0 and 1. A single message consists of a series of numbers, the first one is special and is called the identifier which informs the system what it is. Following the identifier is the information itself and additional numbers at the end form part of the error checking mechanism.

2.1 Considerations for Jaguar's Application

The automotive environment is known to be both physically harsh and electrically noisy, and as such, any communication protocol chosen must be capable of performing under these conditions as well as meeting the requirements of the application. When determining the network architecture for Jaguar's high speed powertrain application, which involves real-time control, the following factors were taken into account :

- ***Latency Time*** : This is defined as the time a transmitting node is ready to send information up until the time the transmission has been completed. Short latency times are essential in real-time control applications.

- ***EMC and EMI*** : The radiated emissions and susceptibility should not effect system performance and be capable of meeting legislative requirements.

- ***Error Handling and Fault recovery*** : Less than one undetected error rate in the lifetime of the vehicle is considered reasonable [ref 1]. The ability to handle and recover quickly from faults was also considered an important factor.

- ***Data Consistency*** : The protocol must ensure consistency of data across the network particularly when sharing sensor information having eliminated duplication of sensors.

- ***Flexibility*** : Because vehicle configuration requirements may differ across model variants and model years, it is necessary that ECU's on the network can be interconnected at different locations within the vehicle without the need to redesign or requalify the system or sub-system.

- ***Expandability*** : Existing systems may need to be upgraded or added to over time. This should be possible without modification of the original system if the additional ECUs are listening nodes, i.e. to data already in existence within the core system. Modification of a sub-system is acceptable to accommodate additional ECU's if it is restricted to software changes only.

The CAN protocol was chosen to meet the demands of the Jaguar powertrain system as it was the only available technology that could realise the requirements of the system specification.

To appreciate the other benefits CAN offers, the following overview is given.

- Expansion and conversion to different configurations are simple
- A multi-master broadcast communications system. That is, every control unit has the same right to access the network
- The CAN arbitration mechanism is entirely independent of system configuration
- No extra provision for start-up is required
- It can take upto 2032 identifiers
- Error recovery is fast
- Upto 1 Mbps (variable) over 40 metres of twisted pair cable
- The arbitration procedure is deterministic in the sense that its outcome can be predicted for any given contention situation
- Latency time is short for high priority messages
- Contention based with no data loss. Simultaneous transmissions are resolved via non-destructive bitwise arbitration. This also provides the message prioritisation. It operates because a dominant bit (logic 0) always overwrites a recessive bit (logic 1), hence if a node transmits a recessive but receives a dominant at the same instant, it knows another higher priority message is also on the bus and therefore stops transmitting. This scenario is shown in Figure 1 below.

Figure 1

NON-DESTRUCTIVE PRIORITISED BITWISE ARBITRATION (EXAMPLE)

NODE 1 : (ID 162)	0	0	0	1	0	1	1	0	0	0	1	0	(ENGINE SPEED)
NODE 2 : (ID 65A)	0	*1	1	0	0	1	0	1	1	0	1	0	(COOLANT TEMP)
NODE 3 : (ID 1B4)	0	0	0	1	*1	0	1	1	0	1	0	0	(VEHICLE SPEED)
BUS :	0	0	0	1	0	1	1	0	0	0	1	0	

* NODE DETECTS LOST ARBITRATION, STOPS TRANSMITTING, AND CONTINUES TO RECEIVE MESSAGE

- Error handling techniques (Cyclic Rdundancy Checking and bit stuffing) for reliable operation in an automotive environment
- Variable data length, 0 - 8 bytes

2.2 Technical Highlights of CAN

CAN was developed by BOSCH in the early 1980's and the first working silicon became available in 1987 after INTEL signed a licensing agreement in 1985. It achieved full ISO standard in 1984[ref 2] and was already approved by the American Society of Automotive Engineers as the standard for the truck and bus industry.

CAN uses a linear bus topology (see Figure 2) which means that every control unit has the same right to access the network, i.e. it is a multi-master broadcast system. Expansion and conversion to different configurations are very simple. However, the constraining factor of this structure lies with the cable length since the maximum length of cable for an application is directly related to, and hence determined by, the rate of data transfer.

CAN is capable of running at 1 Mbps (million bits per second) which enables data transfer to be carried out in a few milliseconds, meeting the needs of the control modules which will use this data. The transfer of data takes place within a CAN message frame (see Figure 2).

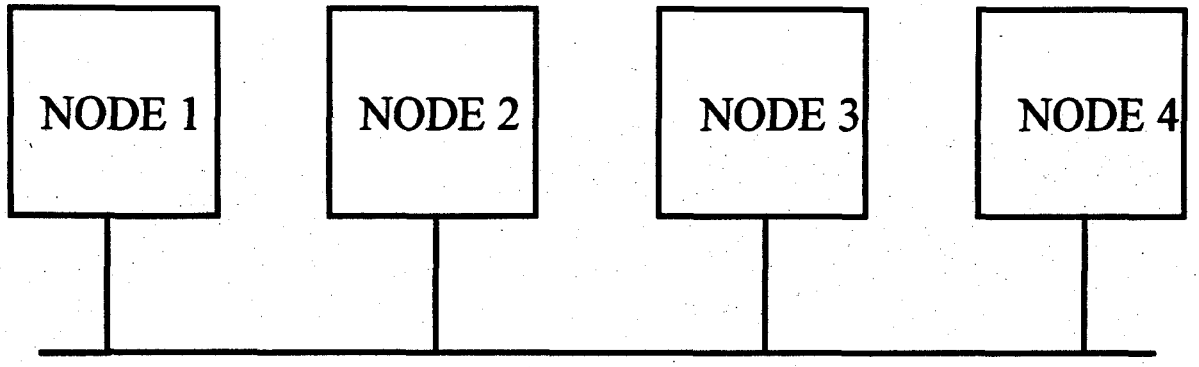
2.3 CAN Message Frames

Communication within a CAN network takes place through a Data Frame. A Data Frame is used to transfer data between nodes. The first field is special and is called the identifier which assigns meaning to the message by defining what it is. The Data Length Code (DLC) indicates the length of the data field. What follows this is the data itself and an error checking mechanism (CRC). The acknowledge (ACK) bit ensures error free transmission has taken place since the assertion of the ACK bit informs the transmitting node that at least one receiver has received the data correctly. If not, an ERROR FRAME is generated and the message is rejected by all nodes. An Error Frame is transmitted if any node on the network detects an error condition during or after a message transmission.

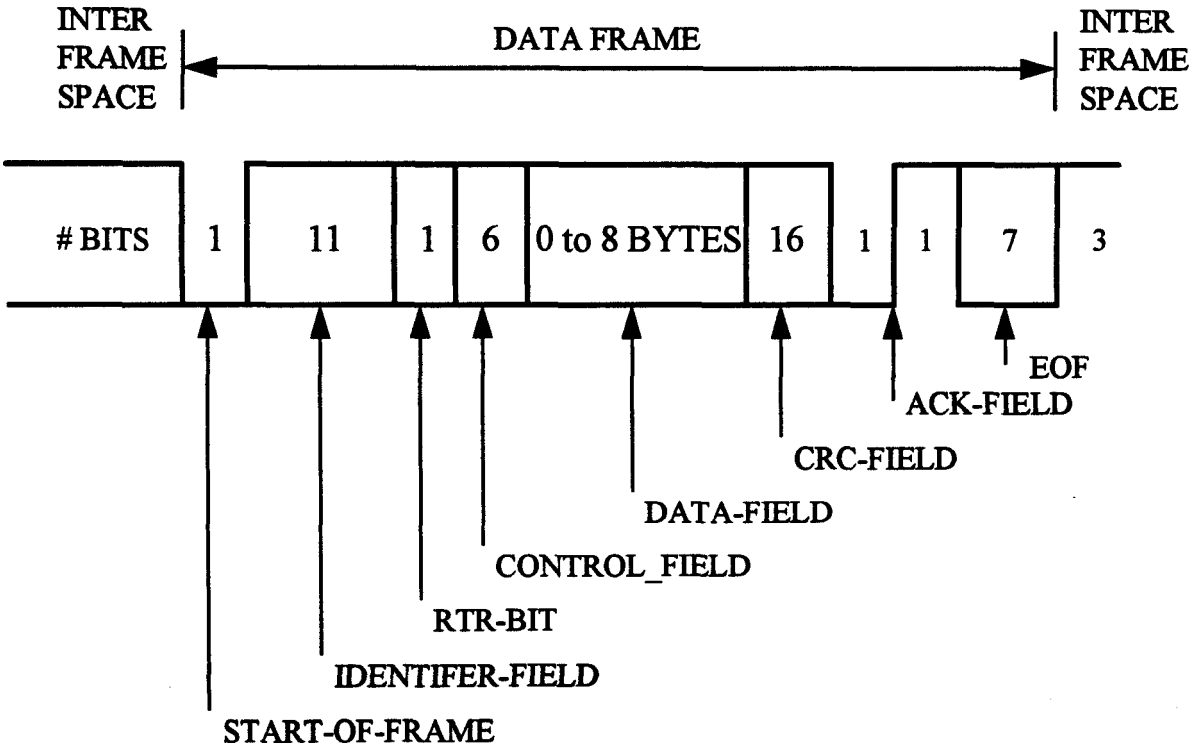
The strength of all this is that it is transparent to the host processor which minimises host processing time. All the host has to do is read and write data into memory slots inside the CAN chip and everything else is performed by the CAN chip. This enables higher level system design to take place without worrying about the details.

Figure 2

LINEAR BUS TOPOLOGY



MESSAGE FRAME

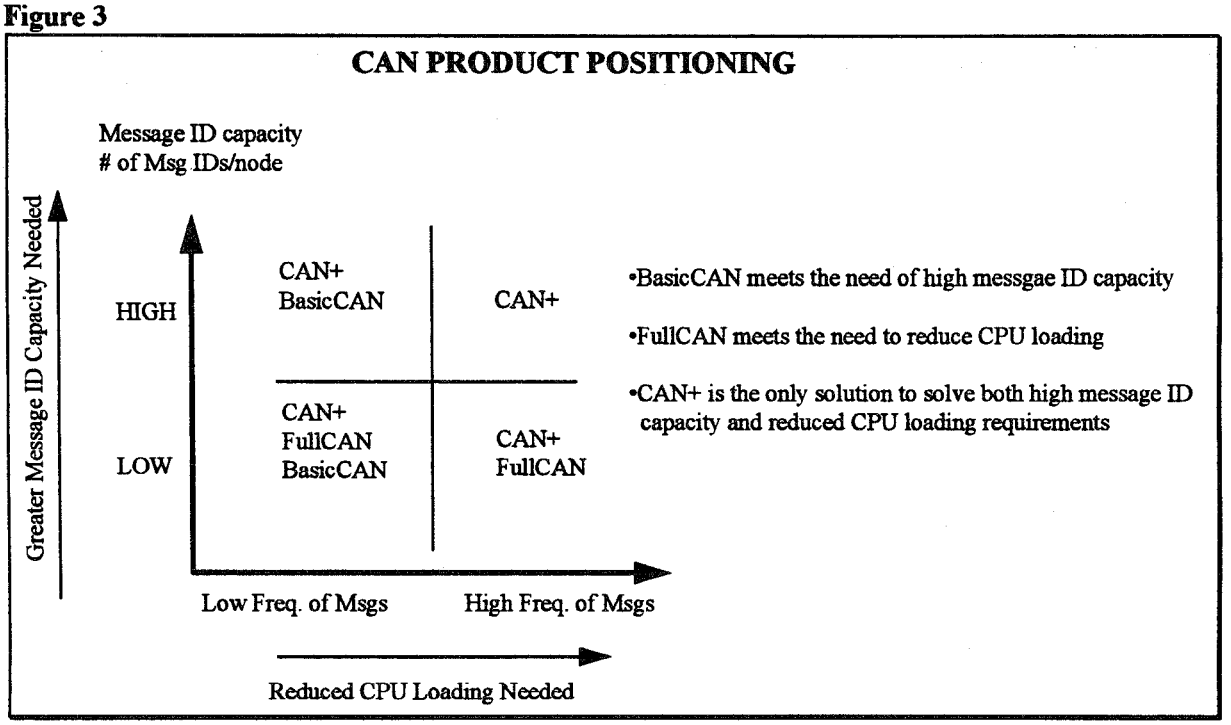


2.4 Implementation of the CAN protocol

A CAN 'chip' can be designed into the electronic circuit of a control module and allow data to be passed in and out of the module via a twisted pair cable linking all the modules on the network together. Chips are available from a number of semiconductor suppliers in a range of forms such that the complexity (and hence cost) of the device can be matched to the application.

There are currently three recognised implementations of the CAN protocol supported by silicon manufacturers known as BasicCAN, FullCAN and CAN+. These are functionally identical with respect to their interface to the bus, but differ in the way the data is buffered inside the chip. BasicCAN is useful where many message identifiers are used, but it incurs a greater host processor overhead by relying on interrupts to service each individual message reception and is therefore suited to non-time critical applications with many message identifiers, for example body system applications. FullCAN does not rely solely on interrupts, but has limited dedicated buffer capacity and hence is useful in applications with few time-critical messages. CAN+ combines the best features of both, allowing some time critical and many non-time critical messages. Figure 3 illustrates how these are positioned in terms of message capacity and the frequency of messages. Jaguar's implementation uses the CAN+ device with the 11 bit identifiers giving 2032 available messages which is commonly known as CAN 2.0A. CAN 2.0B is known as extended CAN and has 29 bit identifiers.

Figure 3



The attractiveness of CAN+ to Jaguar is its capability to handle high performance CAN systems and ability to cater for future requirements. Its memory configuration of 256 bytes has allowed Jaguar's powertrain application to develop in a flexible manner without the memory constraints which would have been imposed with the FullCAN implementation (64 bytes of DPRAM).

3. JAGUAR'S APPLICATION

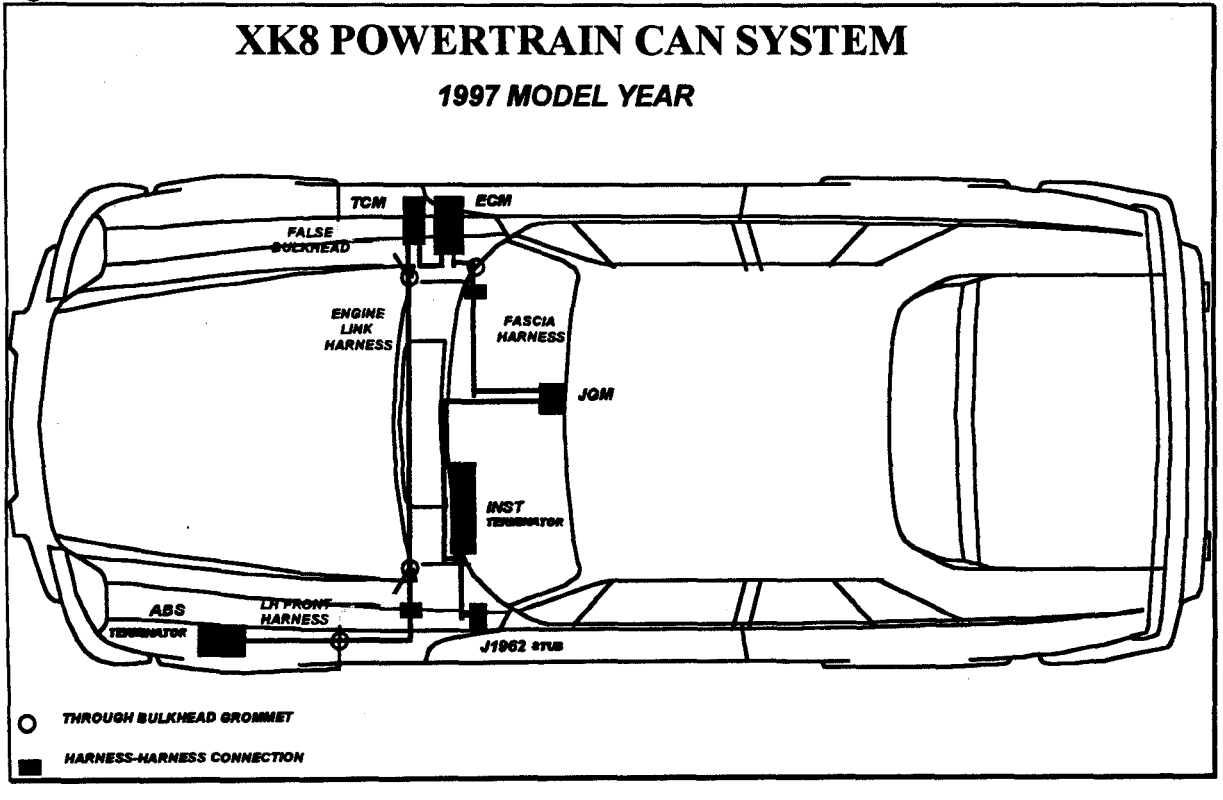
Jaguar's new sports car, the XK8, features the all new AJV8 engine. AJV8 is an advanced 4-litre V8 incorporating sophisticated electronic management and throttle control systems. A CAN communications network is used on this vehicle which links the following systems :

- ECM - Engine Control Module (Denso Japan)
- TCM - Transmission Control Module (ZF Germany)
- ABS - Anti-lock Brakes (Teves Germany)
- INST - Instruments and driver information (FORD ELD USA)
- JGM- J-Gate Illumination Module (AB) : 'listening node only'

3.1 Powertrain Electronics Architecture

The network runs at 500Kbps over a twisted wire pair which facilitates the interchange of information between these ECU's such that they can perform their functions in an integrated manner. This information comprises sensor data, switch data and real time control data. Figure 4 shows the configuration of the system for XK8 as well as the approximate locations of the ECU's and the routing of the CAN bus within the vehicle wiring harness.

Figure 4



The ECU's designated as 'terminators', i.e. those modules at the end of the bus have a 120 Ohm resistor fitted to match the impedance of the twisted wire pair, this reduces reflections which may occur on long bus lengths and at high bit rates.

The object of the system design is to allow the addition or omission of nodes in a modular open system fashion. The network is referred to as 'high speed' to reflect the real-time nature of the information it carries and the bit rate required to meet the response times.

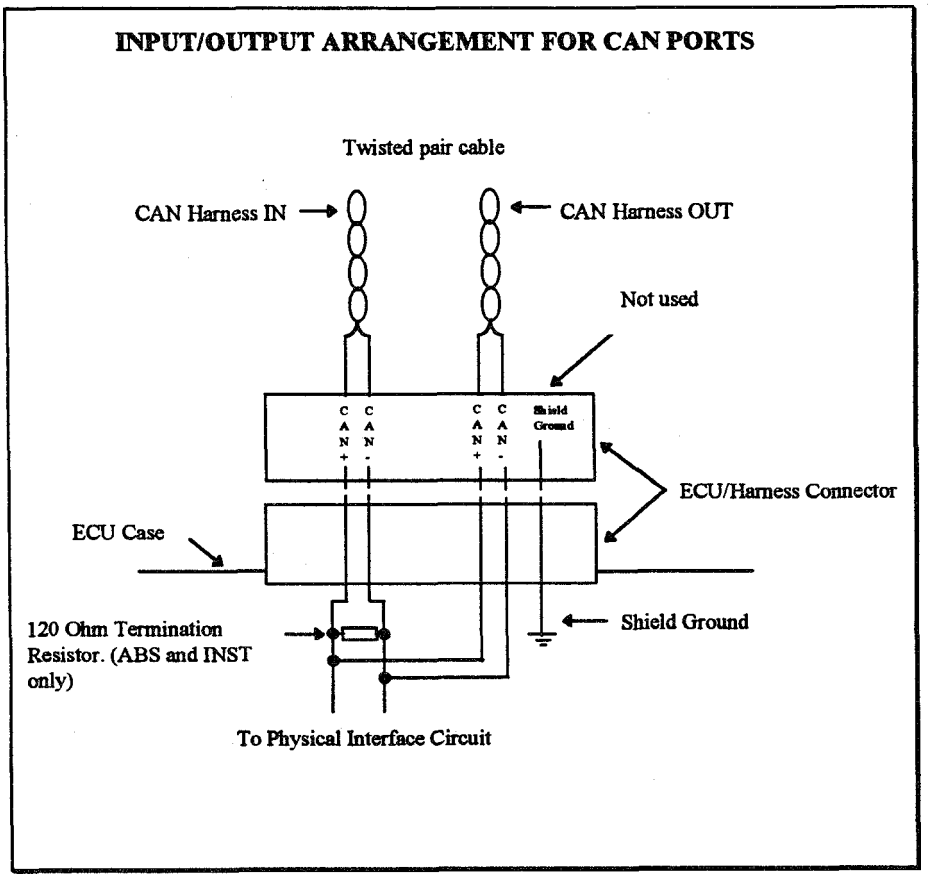
3.2 The Transmission Medium

The CAN wiring harness is a standard 0.5mm unshielded copper twisted wire pair cable. It is configured such that the bus enters and leaves each communicating module via separate input and output terminals.

The connection to the CAN bus is via the normal module block connector. Four pins are allocated on each module which are CAN+ IN, CAN- IN, CAN+ OUT and CAN- OUT.

CAN IN and CAN OUT are joined together inside the ECU via PCB tracks, with the facility for a 120 Ohm termination resistor (see Figure 5 below for a detailed illustration).

Figure 5



3.3 System Design

It cannot be stressed enough that to design a sophisticated and reliable in-vehicle network system it is essential that the requirements of the whole system are considered and fully defined up front. After this has been completed, the requirements of the in-vehicle network system can be described. It is from this philosophy that Jaguar has proceeded.

It follows that the protocol is simply the raw medium for communication which forms the platform upon which the system will operate and perform. Once the protocol has been established and proven to be capable of meeting system requirements, the real challenge lies with the system design. This is by far a more important issue than the choice of protocol.

3.4 Message Infra-Structure

Once the requirements of the system have been determined the network infra-structure can be defined. This involves message packaging, assigning priorities and cycle times.

The packaging of information into messages (up to 8 bytes of data) has several benefits. In terms of the system it allows multiple data to be received at the same time, for example, all four wheelspeeds (each of 2 bytes) can be placed into a single message. This enables related data to be presented at the same time. In terms of the network, message packaging alleviates the traffic on the network which in turn reduces the bus loading. It also utilises the hardware in an efficient and economical manner since the 82527 CAN chip is limited to a total of 15 messages in a system configuration before software management, and hence overhead, becomes necessary.

Once the grouping of information was accomplished, prioritisation was assigned to the messages in accordance with overall system performance timing requirements. Simulations of network traffic were then run to confirm that the timing requirements would be met.

4. NETWORK MANAGEMENT AND FAULT TOLERANCE

4.1 Network Monitor

The network monitor is a novel design solution which has been patented by Jaguar. It is a feature of the system design that has several functions. Its primary role is to determine that the system is functioning normally, i.e. that all the nodes are on the network and the bus is intact.

The reason for having such a feature is so the driver can be warned if a fault exists and other nodes on the network can be made aware of a problem and use appropriate default values. It was considered necessary since there is no inherent way of detecting if a node is disconnected unless each individual message is monitored; this is difficult, inflexible and wasteful.

Jaguar's approach to this problem was to introduce the concept of one special message that is monitored by all nodes. This message would then be realised by a higher level of system software known as the network monitor. The profile of the network monitor is as follows :

Musts

- Capable of detecting an incomplete network
- Recognise incompatibility of electronic modules (wrong part fitted)
- Detect and log intermittent faults

Key Requirements

- Common functionality on all nodes
- Consume minimal processor overhead
- Use minimal traffic overhead
- Respond in under a second
- Inform driver of any problem (if required)
- Locate position of fault
- Allow the use of default values
- Diagnostics

The way in which the network monitor works is that each node has a special message, known as a network monitor "token", which it transmits approximately every 200 milliseconds. The network monitor token contains one byte and is structured such that the upper nibble reflects the vehicle model for which the node is intended, for example:

- '1' - represents XK8

The lower nibble represents the level of system the node is intended for. For example, each time the vehicle progresses to the next development phase the value within the lower nibble will be increased by 1. Checks are performed on the tokens to determine the status of the network.

4.2 Status of Nodes

Each node in the system determines the status of the network approximately once every 500 milliseconds. To do this it checks that it has received the network manager tokens from every other node in the system. Therefore, if a node is functioning then its token (transmitted every 200 milliseconds) should have been received at least twice in this time. If the token from one or more nodes has not been received in the 500 millisecond window, then the network monitor software authorises the default values to be used for the information that is normally received from these 'missing nodes'. If a node is detected as 'missing', but then recovers during the same journey, i.e. the token reappears, it is logged by the detecting node as an intermittent fault.

In order to prevent data inconsistency in the system all four tokens must be of the same value. If one or more tokens received are not equal to the transmitted token then default values are used for the data normally received from these 'inconsistent' nodes. Additionally, the Instrument Pack displays a 'Wrong Part Fitted' message. This also applies to the upper nibble which represents the vehicle model. From production and thereafter such events are only likely to occur during manufacture or service

replacement action. However, during the development stages it served to be an excellent control for maintaining system consistency.

5. DEPENDABILITY

Dependability can be described as the ability to tolerate all levels of network errors/faults without ever preventing the vehicle from starting or operating which was a major factor in the overall powertrain system design. Dependability is an important attribute of a real-time control system [ref 3], and any communications which operate in such an environment must also be dependable. Dependability is a feature of the overall system design and attaining it is over and above what the CAN protocol can inherently offer.

The normal approach to communications system design is to use the 7 layered ISO-OSI model [ref 4]. However, this a theoretical model and in a real-time system such as CAN for powertrain control, it does not help to think of services at all levels of this 7 layer model. Therefore, for this reason the model is simplified to 3 layers: Physical, Transfer and Application as shown in Figure 6.

The application layer contains information used by the ECUs on the network. It is the layer where the data becomes meaningful and its use within the system becomes relevant.

The transfer layer is the part of the system where the techniques for managing the integrity of the network are located. The requirements of the transfer layer are mainly met by software. The requirements are divided according to whether they apply to message level (received and transmitted) or system level (see Figure 7 for further details).

The physical layer is the wires, connectors, transmit/receive interface circuits, and all the associated voltages, currents, resistances and capacitances.

Dependability is achieved by using a number of techniques. To increase the dependability of the physical layer, which is effectively the communication hardware, would be to use redundancy. It was not considered either appropriate or necessary in Jaguar's application to have a dual operational bus, however, by introducing other methods in the transfer layer the appropriate level of overall system dependability can be achieved.

Jaguar's system contains a number of methods aimed at dependability, some of which are supplied by the CAN chip itself, and others which are implemented in software. The techniques used are as follows:

Figure 6

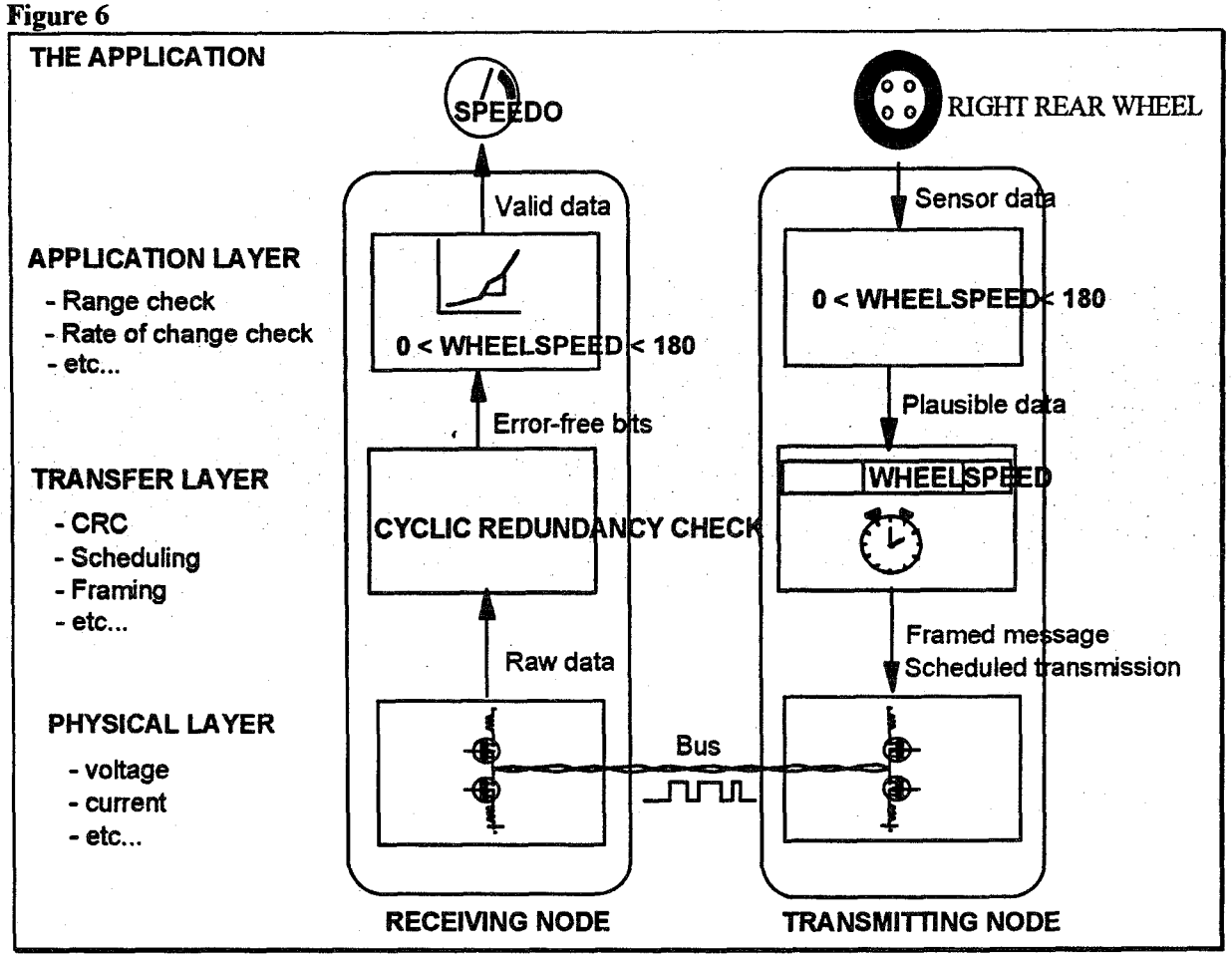
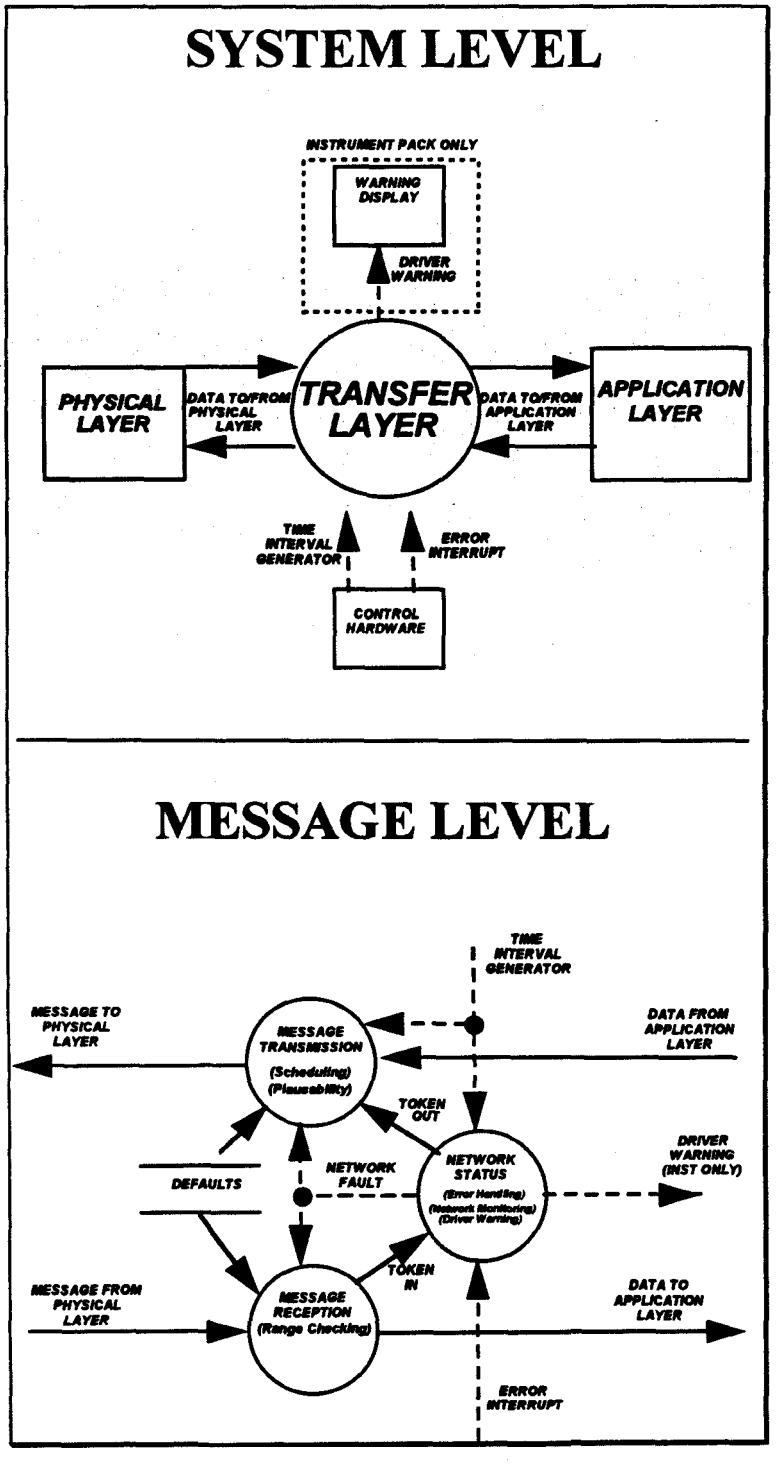

THE APPLICATION
SPEEDO
RIGHT REAR WHEEL
Valid data
Sensor data
APPLICATION LAYER
- Range check
- Rate of change check
- etc...
0 < WHEELSPEED < 180
0 < WHEELSPEED< 180
Error-free bits
Plausible data
TRANSFER LAYER
- CRC
- Scheduling
- Framing
- etc...
CYCLIC REDUNDANCY CHECK
WHEELSPEED
Raw data
Framed message
Scheduled transmission
PHYSICAL LAYER
- voltage
- current
- etc...
Bus
RECEIVING NODE
TRANSMITTING NODE

Figure 7


SYSTEM LEVEL
INSTRUMENT PACK ONLY
WARNING DISPLAY
DRIVER WARNING
PHYSICAL LAYER
DATA TO/FROM PHYSICAL LAYER
TRANSFER LAYER
DATA TO/FROM APPLICATION LAYER
APPLICATION LAYER
TIME INTERVAL GENERATOR
ERROR INTERRUPT
CONTROL HARDWARE
MESSAGE LEVEL
TIME INTERVAL GENERATOR
MESSAGE TO PHYSICAL LAYER
MESSAGE TRANSMISSION
(Scheduling)
(Plausability)
DATA FROM APPLICATION LAYER
TOKEN OUT
DRIVER WARNING (INST ONLY)
DEFAULTS
NETWORK FAULT
NETWORK STATUS
(Error Handling)
(Network Monitoring)
(Driver Warning)
TOKEN IN
MESSAGE FROM PHYSICAL LAYER
MESSAGE RECEPTION
(Range Checking)
DATA TO APPLICATION LAYER
ERROR INTERRUPT

5.1 Scheduling

Each ECU schedules the messages it is required to transmit on a regular and predictable cycle time. This involves a timer and queuing mechanism which allows the highest priority and lowest cycle time messages to be correctly scheduled for transmission. It should be noted at this point that the CAN chip manages the waiting for the 'bus idle' condition before the transmission commences, which is an entirely separate item.

5.2 Bit Level Error Handling

The majority of this is implemented within the CAN chip itself (error detection and correction by retransmission).

5.3 Data Range Checks

Each sensor message has a specified range of valid data; all information that is transmitted and received within the CAN system is checked for a valid data range and is ignored if out of range.

5.4 Plausibility Checks

These are only applied to certain critical signals, and are carried out at source prior to transmission. Hence if the data passes the range check on reception then the data can be considered plausible. The advent of OBDII has now brought greater attention to this area.

5.5 Network Monitor

The network monitor continually assesses the network and decides what state it is in. It has the ability to quickly detect a fault with the CAN network and once a fault has been detected the appropriate default strategy is assumed. It also has another function of indicating the vehicle model and system level thus preventing the fitment of any wrong parts, as discussed previously.

6. CAN AND DIAGNOSTICS

Demanding emission regulations, continually improved quality and increasing customer satisfaction now mean that on-board and off-board diagnostics play a key role in the success of the vehicle and hence the company. Sophisticated diagnostics are managed to full effect to serve both the environment and the customer.

On-board diagnostics provide the self monitoring capability for fault logging, fault reporting and driver information, whereas the role of off-board diagnostics can be visualised as ECU interrogation to establish any identified problems. Off-board diagnostics are used within the manufacturing and service environment.

The majority of component on-board diagnostics, within a powertrain environment, are of an OBDII nature. These diagnostics are governed by legislation issued by the California Air Resources Board

(CARB) - whose mission is to reduce emission and smog in the state of California - to ensure that drivers of vehicles are made aware and then repair their vehicles, when a failure occurs in their emission control system (45% of Jaguar's Federal sales are in California).

6.1 External Diagnostic Session

The Jaguar specific diagnostic methodology is achieved across CAN for the powertrain system and does not qualify as one of the two bus communication techniques which conform to the requirements of the CARB legislation.

The transactions that take place between the powertrain ECU's and the Jaguar Diagnostic System (JDS) follow a master/slave procedure. The master initiates all transactions and slaves never initiate transactions. In all cases the diagnosed ECU is the slave and the diagnosing unit is the master. Diagnostics of the control modules themselves are catered for by allocating two special CAN messages to each node, this enables communication with the external diagnostics tool.

7. BRIEF SCOPE OF BENEFITS

The introduction of an integrated vehicle system using serial communications introduces a series of new opportunities which include harness standardisation and wire reduction, improved system visibility, less operator intervention in the diagnostics process, reduced diagnostic times and improved on-board diagnostics capability.

Harness standardisation and wire reduction improve diagnostics by reducing the number of variant harnesses to be diagnosed around the world, therefore saving on software and development time. In addition, the fault finding algorithms are simplified because of the reduced harness size. Benefits of improved quality from the reduction in harness size and connectors are also realised.

Improved system visibility is a major advantage in diagnostics, particularly in diagnosing systems which interact with other systems on the vehicle. This gives the capability to perform system diagnostic checks by accessing the communications bus and monitoring the inter-system communication in addition to direct connection to the individual ECUs. This reduces the use of previous techniques such a harness probing, T-piece monitoring which can themselves cause damage to vehicles.

In a similar way to diagnostics, an integrated system offers new opportunities to manufacturing. The harness wire reduction improves vehicle assembly and the harness standardisation reduces the parts count. The integration of vehicle systems offers improvements to vehicle electrical tests by allowing single point testing and ECU configuration for the whole vehicle, this makes the vehicle testing time considerably shorter which reduces lead time of the vehicle on the production line.

Furthermore, flexibility is enhanced as the nature of the CAN approach implies that the feature addition can begin at the software phase, thus significantly reducing the lead time to the market place for new features. Competitive edge can therefore be maintained and opportunities of conquest sales can be exploited.

8. CONCLUSION

Feature growth, electronic sophistication and aggressive competition over recent years have made it necessary to provide system integration with high levels of inter-system communication within luxury vehicles to satisfy customer demand. Conventional methods could no longer fulfil this requirement and hence a new technology was needed. Serial communications has proved a suitable technology to take on this role and, although several protocols exist under this heading, the most capable for Jaguar's powertrain system is CAN.

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AN INTRODUCTION TO THE ZF 5HP24 TRANSMISSION CONTROL SYSTEM FITTED TO THE NEW JAGUAR XK8

by P G Whiffin B.Eng. (Hons) A.M.I.E.E.

Project Engineer, Jaguar Cars Ltd

Abstract

The launch of the Jaguar XK8 (codenamed X100), also sees the launch of a brand new powertrain into Jaguar Vehicles. The new powertrain consists of the Jaguar designed AJ26 V8 engine and the ZF fully automatic five speed 5HP24 transmission.

The aim of this paper is to give the reader an introduction to the new features of the 5HP24 transmission control system and an understanding of why a new transmission system was needed.

Introduction

The ZF 5HP24 is the first five speed automatic transmission to be fitted to a Jaguar vehicle and represents a significant step in automatic transmission technology. The importance of this new transmission is reflected in the fact that for the first time a Jaguar vehicle will not be offered with a manual gearbox.

Some of the forces driving the need for an all new transmission are listed below:

1. XK8 would have a brand new engine. A transmission was required to complement the performance parameters of this engine. In particular the transmission must be able to cope with low idle speeds and very high gearshift speeds (in excess of 7000rpm) under high torque.
2. Customer expectations of shift quality and transmission feature content have changed. Customers expect improvement. A quantum leap was required.
3. Fuel economy targets drive the need for five gears and low transmission power losses.

Jaguar has had a long relationship with ZF automatic transmission systems. This new transmission has been developed jointly between ZF and their customers to meet the changing requirements of the luxury vehicle sector.

The 5HP24 also features a brand new control system and shift control strategy which is significantly different to conventional four speed systems. New features include:

1. Full closed loop control of shift energy management, in real time.
2. Overlap gearshifts.
3. Driving situation recognition.
4. New 32-bit TCM with C.A.N. (Controller Area Network) on board.

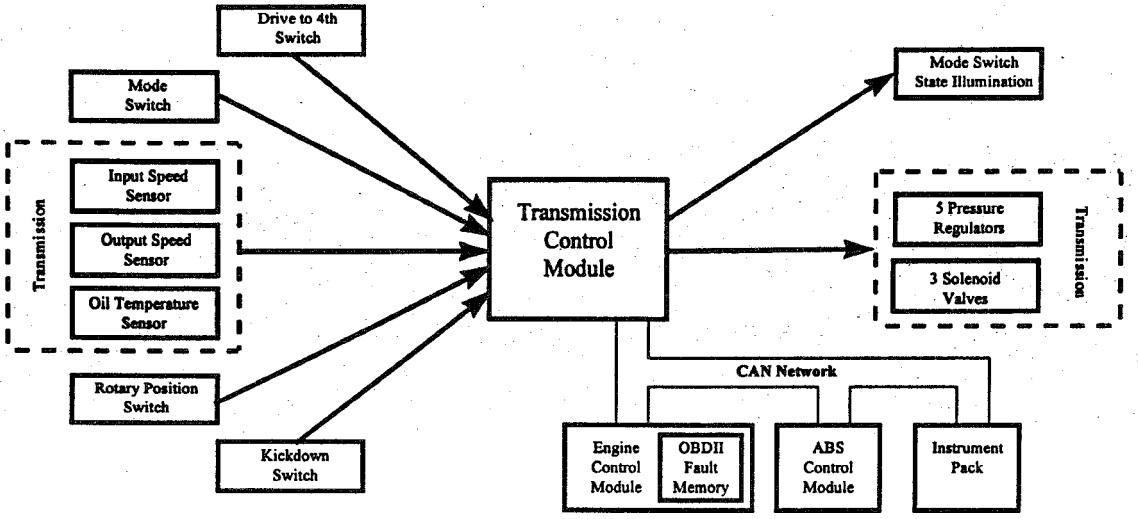
These new features will be discussed in the following sections.

Control System Overview

The Transmission Control Module (TCM) controls the operation of the transmission. The TCM receives information in both analogue and digital form and uses this information to select the most appropriate gear for the current conditions. Figure 1 shows an overview of the transmission control system.

The TCM also monitors the transmission system for correct operation and is able to diagnose faults and take appropriate action when needed.

Figure 1



The TCM controls the transmission by operating the solenoid valves and pressure regulators which control the flow of transmission fluid to the various clutches.

The most obvious differences between this and a typical system diagram of an older transmission system are the larger number of pressure regulators/solenoid valves and the addition of the C.A.N. high speed serial communications network.

Gearshift Control

Electronically controlled overlap gearshifts are used on all shifts except First to Second. First is the only gear with a freewheel clutch, since at the low speeds the first to second change occurs, the accuracy of the data from the input/output speed sensors is limited. All the shifts are completely closed loop controlled so that a consistently high shift quality can be guaranteed through the service life and production tolerances.

Conventional 4-speed transmissions use just two solenoid valves (on or off valves) for gear selection, with the old clutch pack being disengaged before the new clutch is engaged. A simple truth table of the solenoid valves state would immediately indicate the gear selected. This transmission uses five pressure regulators and three solenoid valves and a simple truth table would not indicate which gear is selected. This is because the pressure regulators are not simply "on or off", but allow the pressure to the clutch packs to be balanced to give the appropriate gear.

Overlap shifts mean that neutral is not selected between gears. Pressure is applied to the "next gear" clutches as pressure is reduced on the "old gear" clutch packs. This requires a high TCM processor overhead as the two clutch pressures must be balanced throughout the gearshift to give a high shift quality and protect the transmission from damage. The advantage of this system is that drive is not interrupted, torque is always applied to the wheels throughout the gearshift and greater shift quality is possible.

Since there is no neutral between gears, the gearshifts are no longer hydraulically protected. Hence, the TCM monitors the change characteristic for anomalies. If the shift does not match the specified characteristic (rate of change of input and output speeds etc.) then the gearshift is aborted to prevent transmission damage.

Overlap shifting is only possible using a high speed communications link to the engine management system so that shift energy management can be closed loop controlled in real time. Shift energy management allows the transmission to control the engine output torque during a gearshift, so that excess power is not dissipated in the transmission friction elements during the shift. The functions of shift energy management are:

1. Increasing the transmission life by shortening the slipping time.
2. Improving the shift comfort by reducing the step change in torque caused by the gearshift.
3. Limiting the maximum engine power transferred into the transmission.

There are four basic control strategies for overlap shifts, depending on the type of gearshift, these are discussed below:

1. Upshift Under load

Figure 2

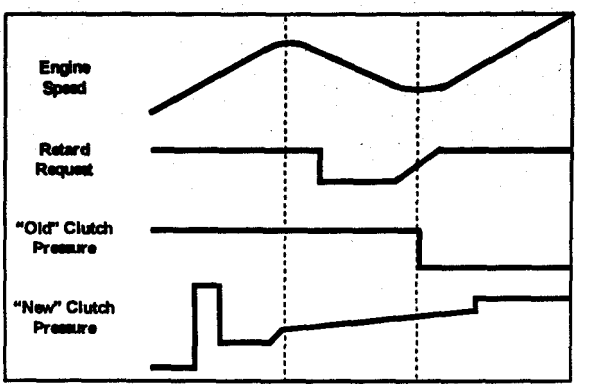
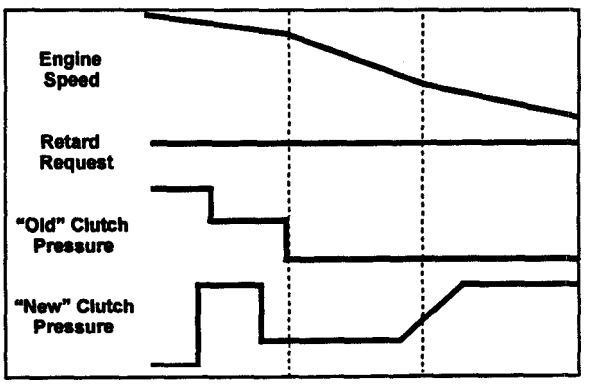


Figure 2 shows an example of an upshift under load. The first vertical dotted line indicates the start of the actual shift, the second the "synchronisation point" almost at the end of the shift. Prior to the shift beginning the TCM applies a high pressure pulse to the "new" clutch set. This quickly pre-fills the new clutch with transmission fluid and brings the clutch to an almost engaged state. As the change begins the pressure applied to the new clutch is increased, gradually engaging. At the same time ignition retard is applied to help reduce the engine speed, increasing clutch life. During this period the pressure on the old clutch is maintained. The pressure on the old clutch set is reduced once the synchronisation point is reached and the ignition retard is ramped off. Once the pressure on the new clutch reaches the desired level the shift is complete.

2. Upshift Without Load (Coast)

Figure 3

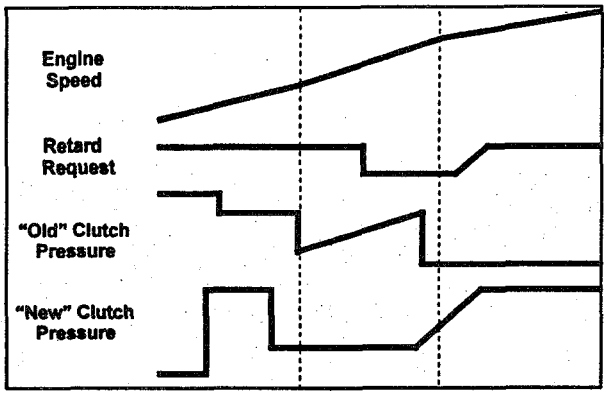


The control strategy for a gearshift without load is significantly different (see Figure 3). The most obvious difference is that no torque reduction is required as the engine speed drops on it own. The shift sequence

starts with the "normal" pre-fill of the new clutch, to bring it to the just disengaged state. The old clutch is then completely disengaged during the shift. The new clutch is engaged gradually just before the synchronisation point. It can be seen that the control strategy for an upshift without load is much simpler than an upshift under load.

3. Downshift Under Load

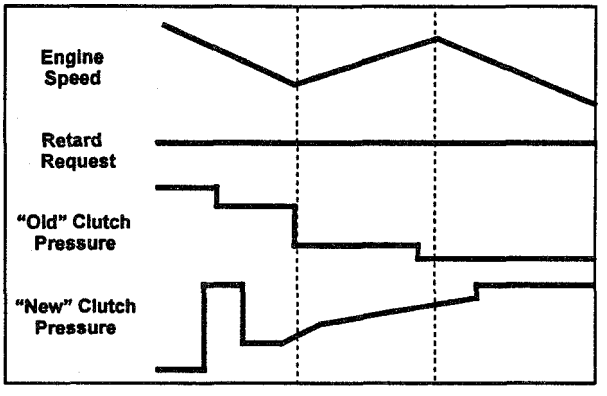
Figure 4



A typical trace for a downshift under load is shown in Figure 4. The new clutch is pre-filled as before. The graph shows the old clutch pressure ramping upwards during the gearshift, this is because the engine torque is changing during the gearshift and the TCM compensates to keep the old clutch just engaged. Ignition retard is used to control the engine torque. The old clutch is disengaged just prior to the synchronisation point, as the new clutch is engaged. The retard request is then ramped off to give a smooth transition, otherwise there would be a shock as the new clutch set is engaged.

4. Downshift Without Load (Coast)

Figure 5



The last class of shift is a downshift without load (Figure 5). Like all shifts, it begins with a pre-fill of the new clutch. The old clutch is kept just engaged to ensure the engine speed does not change too quickly, so giving a smooth shift. The new clutch is ramped on, causing the engine speed to rise. The time between the new clutch beginning to engage and the synchronisation point is critical. If this is too short the shift will be uncomfortable, if too long the vehicle will slow down. The old clutch is disengaged just prior to the synchronisation point.

Driving Situation Recognition

Special shift maps are available, which are designed to enhance the operation of the vehicle, under very specific operating conditions. The shift maps are as follows:

Table 1 "Specific" Condition Shift Maps

Priority (1=Highest)	Program Name	Operating Condition
4	Cruise	During cruise control.
1	Traction	When traction intervention is active.
3	Gradient	Under specific speeds and load.
2	Hot Mode	Extreme Engine/Transmission temperatures.

The "specific condition" maps have higher priority than the basic sport/normal shift maps, i.e. whenever the specific entry conditions for each of the three maps arise the TCM will enter the appropriate traction/cruise/gradient map.

The Traction map is intended to compliment the traction control system. The TCM will implement the Traction map whenever traction control intervention (either engine or brake) is taking place. The aim of the map is to maximise stability under wheel slipping conditions. This is achieved by minimising gearshifts and shifting and the smoothest point in the engine speed range.

The Cruise map is intended to reduce unwanted gearshifts and "hunting" during cruise control operation. The map is activated when cruise control is resuming or cruising near the set speed. This shift map contains extra hysterisis about the shift points.

The Gradient maps are intended to enhance the driveability of the vehicle when climbing a gradient. The maps are implemented when increased driving resistance is detected by the TCM. The TCM monitors acceleration and vehicle torque and compares the actual acceleration against its internal vehicle model. If the acceleration is below the calculated threshold then gradient mode is enabled. This map is calibrated to give increased vehicle performance, enhanced driveability and improved cooling performance under gradient conditions.

Under extreme high temperature conditions, when either the engine coolant or transmission oil temperature exceed set thresholds, the TCM enters Hot mode. In this mode the TCM adopts a shift and torque converter lock-up strategy to minimise the heat introduced into the vehicle cooling system by the transmission. The torque converter is kept locked whenever possible and lower gears are selected.

Legislated Diagnostics

An attractive feature of the OBDII diagnostic system on the XK8 is that it is an entirely integrated system rather than each ECU diagnosing it own components in isolation.

All OBDII fault information is passed immediately to the Engine Management Control Module (ECM). The ECM holds the legislated fault memory for the entire system and controls the Malfunction Indicator Light (MIL). All information is transferred over the CAN network.

The TCM passes the fault code to the ECM, with the following information (flags):

1. Fault Temporary or Permanent Flag (i.e. First or second fault cycle).
2. Emission effect flag (i.e. Does fault effect emissions by > 15%?).

The TCM also monitors the fault cycle logic for each of its emission failures so that MIL illumination can be controlled by the ECM. This is required since legislation states that the MIL need not be illuminated until the second drive cycle in which the diagnostic test has been completed and failed. The legislation also requires

the MIL to stay illuminated for a further three drive cycles, in which the diagnostic is completed and passed. The TCM, therefore, continues to transmit the fault code to the ECM for the required additional time.

The reason each ECU monitors it own fault cycle logic, and not the ECM, is as follows: Each individual fault will have a different fault cycle. For instance, to complete a torque converter diagnostic it my be necessary to test in the locked state. Only the TCM can tell when the test conditions are met, so only the TCM can monitor the fault logic.

The flags transmitted above allow the ECM to pass to the OBDII scantool all the information required by legislation.

Additional Diagnostics

In addition to meeting all the OBDII diagnostic requirements for fault storage and freeze frame data, the TCM also has its own fault memory and diagnostic functionality for non-emissions related failures.

For each and every fault the TCM stores freeze frame data which is tailored to the specific failure. For instance, for electrical failures the supply voltage at the time of failure would be recorded. Three items of freeze frame data are stored for each fault.

The TCM also stores the following information for each fault (and keeps up to date):

1. How many times the failure has so far occurred.
2. Is the fault present now?
3. Is the fault intermittent?
4. Has the diagnostic test for this fault been completed in this drive cycle?
5. Fault type (short circuit high/low, open circuit, rationality check etc.)

This information is designed to aid quick and efficient rectification of the failure.

All the fault information is kept in EEPROM memory so that, even if the TCM is removed from the vehicle, fault information is not lost.

Safety Functions

The safety functions are designed to safeguard against maloperation by the driver as well as against system malfunctions. The maloperation system prevents reverse gear from being engaged at high forward speeds and prevents manual downshifting at excessive engine speeds. These functions are not operational in mechanical limp-home mode.

Great attention must always be paid to safeguarding against, and detecting, malfunctions in the electronic control system. Consequently, the mechanical connection between the selector lever and transmission is retained. Hence, it is not possible as a result of any fault in the electrical system, for reverse or any forward gear to be selected whilst the selector is in the neutral position. The design of the electrical and diagnostic system must be such that system integrity is protected at all times, the safety concept being based on the following three points:

1. The hydraulics system has "fail-safe" characteristics regarding its electrical energisation, i.e. as a result of the power supply being lost to the electro-hydraulic actuators the transmission moves into a reliable emergency limp-home mode.
2. Recognition of critical shift operation by monitoring the last element in the signal path, i.e. the solenoid valve, and checking by means of redundant measured variables, i.e. engine speed, input speed and output speed.
3. Measures which guarantee a high degree of availability of safeguard functions, i.e. monitored safety circuits. For this purpose each time the vehicle is started there is a check on the entire safety hardware and the associated program parts and signal paths. A malfunction in this part of the system, or triggering of the safety circuit, is communicated to the driver through the illumination of the transmission warning lamp.

CAN Communications System

A very significant improvement over old systems is the introduction of the CAN network onto the vehicle. The new TCM is the first generation of new breed of control module which include the hardware and software to enable it to communicate over the CAN network.

The CAN network is a real time, high speed, communications network. This allows the ECU's connected to the network to exchange real time control and data information. Thus the ECU's can operate more as a single system, rather than separate units and considerable synergies are therefore obtained.

Although the advantages of this system are huge, great care must be taken during development. Once such a network exists, the possibilities for inter-ECU control strategies grow exponentially, and it is important that all the ECU suppliers on the network fully understand the meaning of all the CAN messages and react as expected by the other ECU's. Rigid control must be therefore maintained over the CAN network by a central source, in Jaguar's case this was achieved by a separate CAN team.

The other ECU's on the CAN network are:

Engine management
ABS/Traction Control
Instrument Pack
J-Gate Module (Listening only)

An example of some of the information received and transmitted by the TCM is shown in Table 2

Table 2

Inputs	Outputs
Traction Control Status	Torque Reduction Request
ABS Malfunction Flag	Transmission Overload Flag
ABS Status	Input Speed
Estimated Engine Torque	Output Speed
Throttle Position	Torque Converter Slip
Pedal Position	Kickdown Status
Torque Reduction Acknowledge	Actual Gear Selected
Engine Speed	Gear Selection Fault Flag
Cruise Control Status	Shift Map Selected
Engine Coolant Temperature	Transmission Oil Temperature
Engine MIL Status	Transmission Malfunction Message
Engine Fault Codes	Transmission Fault Codes
All Wheel Speeds	

Improvements Afforded by CAN

An example of the improvements afforded by the CAN link is shift energy management.

During gearshifts the engine torque is reduced both to improve shift comfort and gearbox durability. The CAN network allows the TCM to request an exact torque reduction value, and then the ECM to respond with exactly the torque reduction it is actually achieving. If the ECM is unable to fully achieve the requested

torque reduction the TCM is able to react to this immediately and change the pressure applied to the clutches in real time. The TCM is also able to modify its torque reduction request through the gearshift. In this way the torque of the engine can be exactly matched to the hydraulic pressure applied to the friction elements all the way through the shift. A significant improvement in shift quality can therefore be obtained. Such real time inter-ECU control is only possible with the introduction of the CAN network.

The CAN network also aids diagnostics. Extra signal redundancy improves the system response to failures or makes failures easier to detect. For instance the TCM is able to use either output speed or rear wheel speed (from the ABS module via CAN) information. In the event of a failure of the output speed sensor, which would previously have resulted in "limp-home" mode, the TCM is now able to switch to rear wheel speed and transmission operation is not affected.

New Transmission Control Module

The introduction of the 5HP24 transmission also sees the introduction of a brand new TCM. The hardware for this TCM was developed by Bosch and the software by ZF and Bosch in accordance with Jaguar's specification.

Hardware

Current generations of TCMs have included 8-bit micro-controllers, which have had sufficient processing power for previous applications. The introduction of many new real-time control strategies, such as overlap shifts, meant that more processing power was required. To meet these requirements a powerful 32-bit TCM was developed.

The specification of the new TCM is shown in Table 3.

Table 3 TCM Specification

Controller	MC68332 (32-bit)
Clock Frequency	16MHz
External Program Storage	128 or 256 Kword (16bit)
Diagnostic Storage	256 bytes (EEPROM)
CAN Controller	82527
External SRAM	8 Kbyte
External A-D Controller	10 Analogue Inputs

Not only is the new TCM quicker and more powerful than previous models, but by using greater integration and new technology it has also been possible to decrease the size of the TCM, whilst increasing the number of features

Figure 6

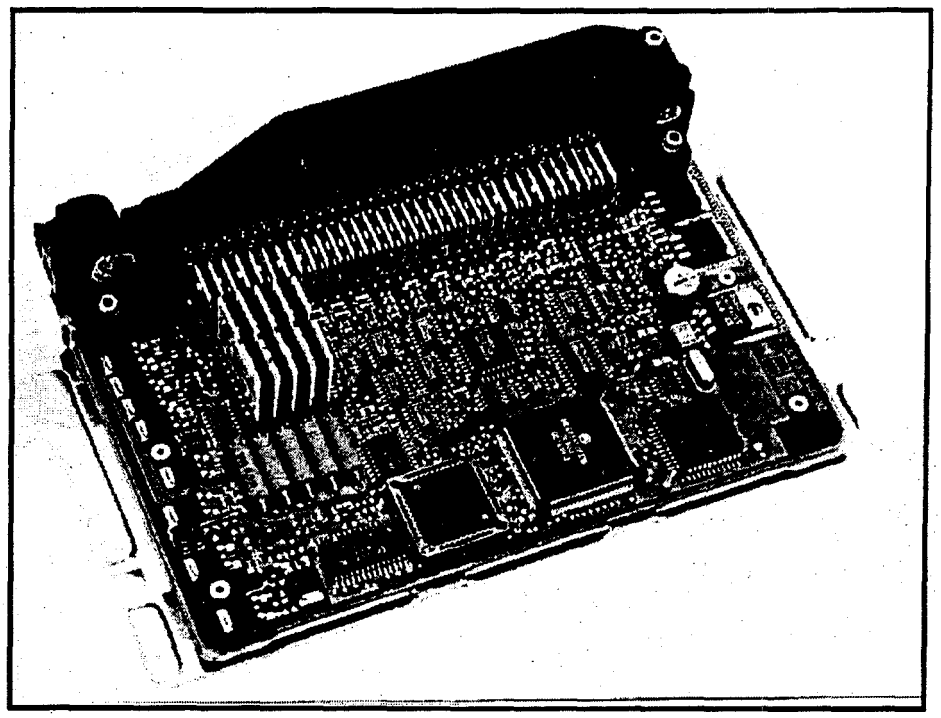


Figure 6. shows a picture of the new TCM with the case removed.

The largest integrated circuit at the bottom of the board is the Motorola microprocessor (a large black square). To the right of this is the CAN controller. To the left of the microprocessor is the PROM, which contains the program and calibration data. The TCM also contains a 256byte EEPROM so that data can be stored after power-down. This is used to store fault information and variant configuration.

At the top left of the main board can be seen five vertical hybrid boards. These are the pressure regulator drivers. The case itself acts as a heatsink. There are special tracks and holes cut into the board, which are in contact with the case, to conduct heat away. The circuit board itself is double sided, with additional components on the underside.

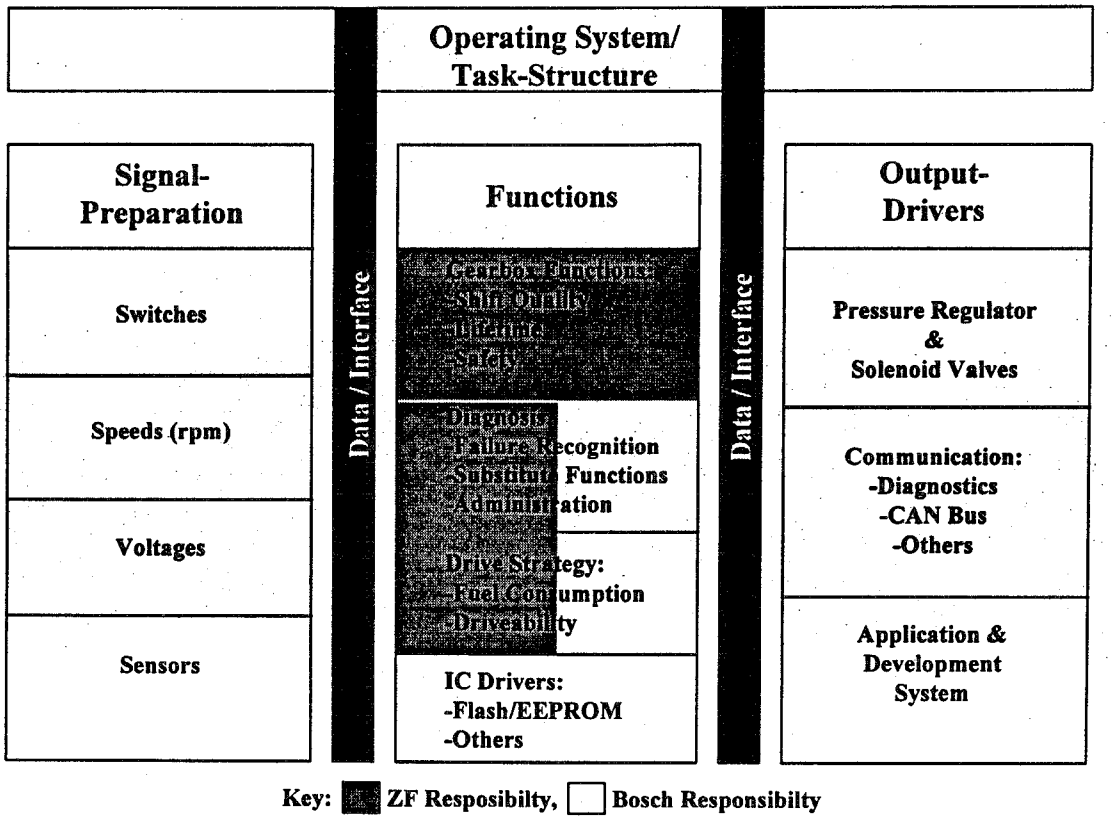
Software

A new approach has also been used to write the software for the transmission system. For the first time software sharing has been introduced between ZF and Bosch, each responsible for certain software modules. The reasons for choosing to develop the system in this way are as follows:

1. ZF have transmission control expertise.
2. Bosch have hardware and control unit expertise.
3. Each can then write the software module in which they have the greater knowledge.

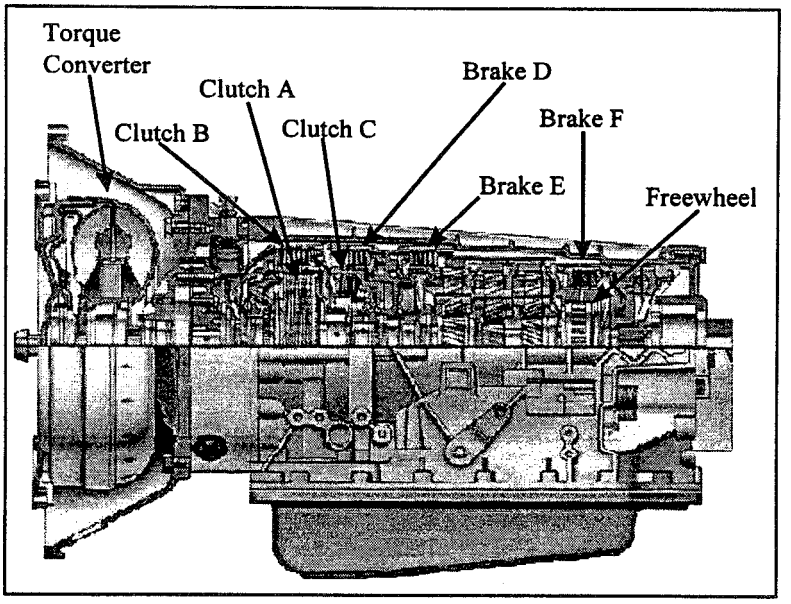
Thus, major synergies can be developed. An overview of software responsibilities is shown in Figure 7.

Figure 7



A Brief Review of the Mechanical Transmission System

Figure 8 5HP24 Transmission Diagram



The development of the new Jaguar V8 engine led to a demand for a new five speed automatic transmission, the 5HP24, which was specially adapted for this engine. The transmission concept was centred around the tried and tested ZF 5HP30 production transmission based on Wilson planetary gearing. This set-up means

that all gearshifts (including double downshifts) are possible with just three clutches and three brakes. Table 4 shows which shift elements are closed in each gear.

Table 4 Shift Elements Closed in Each Gear

	Clutch			Brake			Freewheel
Gear	A	B	C	D	E	F	
1	■					■	■
2	■				■		
3	■			■			
4	■	■					
5		■		■			
R			■			■	

Key - Shaded area indicates shift element closed in given gear.

Considerable importance was placed on the reduction of transmission power losses and noise levels.

The transmission has been designed to cope with both low input speeds (to allow low engine idle and to meet emissions regulations) of 500rpm and high input speeds, at which gearshifts can still occur, in excess of 7000rpm.

The wide gear ratio spread, overdrive top gear and low inertia torque converter fully satisfied the exacting performance requirements for off-the-line acceleration, high maximum speed and fuel economy

Table 5 5HP24 Specification

Transmission	5HP24 5 speed automatic
Torque Converter	With slip controlled lock-up clutch; Torque from 120Nm to 300Nm at 2000 RPM
1st Gear Ratio	3.57 : 1
2nd Gear Ratio	2.20 : 1
3rd Gear Ratio	1.51 : 1
4th Gear Ratio	1.00 : 1
5th Gear Ratio	0.80 : 1
Reverse Gear Ratio	4.10 : 1
Lubrication System	Maintenance Free
Weight (with oil)	95Kg

Torque Converter Clutch

The torque converter clutch developed for the 5HP24 has a high power to weight ratio as well as a high level of hydraulic efficiency. The converter clutch piston is spring loaded to ensure good converter engagement

quality. The TCM is able to operate the clutch in closed loop "slip controlled" mode as well as fully open or closed. In slip controlled mode a small level of slip is allowed by the TCM, thus improving driver comfort, by increasing the transmissions ability to absorb driveline shunts, without sacrificing fuel economy.

To avoid noise, a tangential spring component configuration was selected for coupling the torque converter clutch piston. This prevents circumferential play and therefore noise.

An increasing friction coefficient is required against the speed differential to ensure the slip controlled converter clutch can be controlled without friction vibrations (shudder). The friction coefficient characteristic is determined by the properties of the steel friction surface (the lining) and the oil. During development of the coating, the objective was to achieve a friction coefficient which is as constant as possible throughout the coating lifetime. To prevent an unfavourable friction coefficient on a new coating which had not worn in, and therefore avoid "green shudder", the wearing in process is performed during manufacture of the coated discs using high temperature treatment.

Hydraulic System

The functions of the hydraulic system are as follows:

1. System pressure setting with respect to turbine (input) torque.
2. Individual clutch control corresponding to data from transmission electronics.
3. Lock-up clutch control.
4. Providing the transmission with cooling and lubricating oil.
5. Emergency gear control (limp-home mode) in case of power failure or malfunction.

The hydraulic system is based on the known design of the 5HP30 transmission, although improvements have been made to hydraulic control valves and actuators. The hydraulic control valves are made of aluminium covered with a hard coat layer.

All actuators are fitted with a filter in the access duct so that, in the event of dirt finding its way into the transmission oil, the system is protected.

The capacity to cope with low input speeds determined the size of the internal oil pump (crescent pump). To cope with the high speeds required, the excess oil flow from the pump flows back to the intake side of the pump via a flow control valve. This prevents power losses and ensures cavitation free operation up to maximum speed.

The compact arrangement of the engaging clutches ensures that pressurised oil can be supplied via just six dynamically sealed rectangular rings. This also gives a further reduction in drag torques.

Electrical System

The transmission contains five pressure regulators and three solenoid valves.

The load dependant system pressure, the clutch control valves and the lock-up clutch are energised by the five pressure regulators. These are 2/2 proportional valves. These have been optimised with regard to cold weather behaviour and precision of control.

The solenoids are used to actuate the auxiliary valves and are 3/2 electrical valves. The valve response time and flow rate were optimised in order to obtain improved response behaviour.

Table 6 shows which of the solenoids valves and pressure regulators are used in each gear. Pressure regulator four controls the lock-up clutch.

Table 6 Which Solenoid Valves and Pressure Regulators Are Used in Each Gear

	Solenoids			Pressure Regulators				
Gear	1	2	3	1	2	3	4	5
1	■			■				■
1P	■			■				■
2	■	■		■			■	■
3		■		■			■	■
4		■		■	■		■	■
5			■		■		■	■
N/P	■							■
R-S	■		■					■
R		■				■		■
		■				■		■

Summary

Our aim was to deliver to the customer a "best in class" transmission system" befitting the new Jaguar XK8. This has been achieved through:

1. A brand new transmission, the 5HP24
2. A new "state of the art" 32-bit Transmission control module.
3. A new shift control strategy, overlap shifting.
4. C.A.N. Serial communications, allowing real time information interchange between modules.
5. Joint software development between ZF and Bosch, sharing expertise.
6. The introduction of new features, such as driving situation recognition.

It is hoped that this package will deliver the quantum leap required to make an impact on customer perception and that Jaguar will become the marque which other manufactures benchmark against.

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ZF Technical Information	P Wendel, H Bauknecht and G Gierer
AJ-V8 Brochure	Jaguar

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K Thiele Dipl. Ing, Electronic Transmission Control (Robert Bosch GmbH)

C Schmidbaur Dipl. Ing, Development Software/Hardware (ZF)

THE DESIGN AND DEVELOPMENT OF THE XK8 CHARGING SYSTEM

by

Stephen Pickering, Electrical Engineering

1. INTRODUCTION

An automobile charging system appears at first to be a very simple system. It basically consists of a rechargeable storage battery that is used to start the vehicle and a generator which is used to ensure that the battery is recharged. However, this simple system can be difficult to implement due to the following, often conflicting, requirements and limitations:-

- In addition to charging the battery, the generator must also be able to supply the electrical power requirements of the vehicle. These power requirements vary dramatically with climatic conditions and vehicle specification, (heated screens, air conditioning systems, electric cooling fans etc), and can be as high as 2 - 3KW. With improving engine efficiency, average engine speeds are tending to fall so as to enhance fuel consumption and vehicle refinement. Also, due to increasingly tightly packaged and sealed engine bays, the generator can experience high temperatures, even in Winter conditions. Unfortunately, the output power of the generator reduces with increasing temperature and reducing engine speed so the modern automobile is an increasingly hostile environment for the generator.

- The battery must contain enough power to drive the starter motor at a high enough speed and for a suitable time to start the engine under any climatic conditions. Unfortunately, the chemical activity of a battery reduces with temperature such that, at very low temperatures, its output power capability can be reduced by up to 50%. However, with more advanced engine management and fuel systems, engines are now able to be started in a shorter time and with lower crank speeds than was the case for carburettor fed engines. This improvement, though, is more than offset by increasing vehicle electrical complexity, which leads to greater demand for the battery to support electrical systems while the car is switched off, (eg alarms, engine management systems, navigation systems etc). While the demanded current is usually only in the order of mA, it can have a significant effect upon the state of charge, (and therefore output power capability), of the battery if the vehicle is left for a long time. Consequently, the battery size is now driven more by such 'Key Off Loads' than by the vehicle starting requirements.

- The vehicle cost, fuel consumption, performance and refinement are affected, to different degrees, by the size of the battery and the generator so, whilst the charging system would ideally consist of a battery powerful to satisfy the above requirements and a generator big enough to ensure it is never discharged, such components would be large and heavy and not used to their full capacity for the majority of the vehicles life. The resultant charging system would therefore reduce vehicle efficiency and increase its lifetime cost to the customer. In order to minimise their impact on the vehicle, it is necessary to choose the smallest and most efficient components possible that will still ensure that the customers, wherever they live, will always be able to start the vehicle whilst incurring the lowest cost penalty possible.

This paper will describe the process by which Jaguar provides the optimal charging system for its vehicles, and concentrate upon the simulation tools used to enhance this process and allow the components specification to be fixed as early as possible in the design process.

2. FACTORS AFFECTING COMPONENT CHOICE

Battery

1. Power required to start the engine. This is defined by the starter motor used, the effectiveness of the engine management system and the friction characteristics of the engine.

2. Power required to support vehicle systems when left standing. This is determined by the total current draw of the vehicle Key Off Loads and the required time for which the vehicle may be left and still start.

3. Battery Dynamic Performance. This is the ability of the battery to operate satisfactorily throughout the vehicle life and covers such factors as energy throughput, deep discharge recovery, charge acceptance and operational environment. It is not a factor that can be defined without question and forms a central area of investigation during the design and development of a charging system.

Generator

For present car electrical systems the generator must provide a nominal 12V DC power output. Therefore, it may either generate DC power directly, (a dynamo), or generate AC power which is then rectified to DC, (an alternator). The alternator uses brushes moving around smooth slip rings to provide power to its rotor, so it's brushes do not wear as quickly as those of a dynamo, which move around a commutator. As a commutator comprises a number of separate segments, the brushes of a dynamo suffer higher electrical stress due to current fluctuations and sparking as they move between segments and mechanical wear due to passing over the segment edges. Also, modern vehicles tend to have engines with high maximum and transient speeds in addition to carrying increasing electrical content. This leads to higher generator speeds being required in order to be able to supply the necessary electrical power. The dynamo cannot economically attain the speeds required by modern vehicles due to commutator and rotor construction limitations. However, as the alternator is basically an AC generator it has no commutator and the rotor construction used for such machines is more robust and capable of much higher sustained and transient speeds than a dynamo. The alternator is also able to provide a higher power density thus allowing a smaller and lighter package to be obtained than for a dynamo with a similar power output.

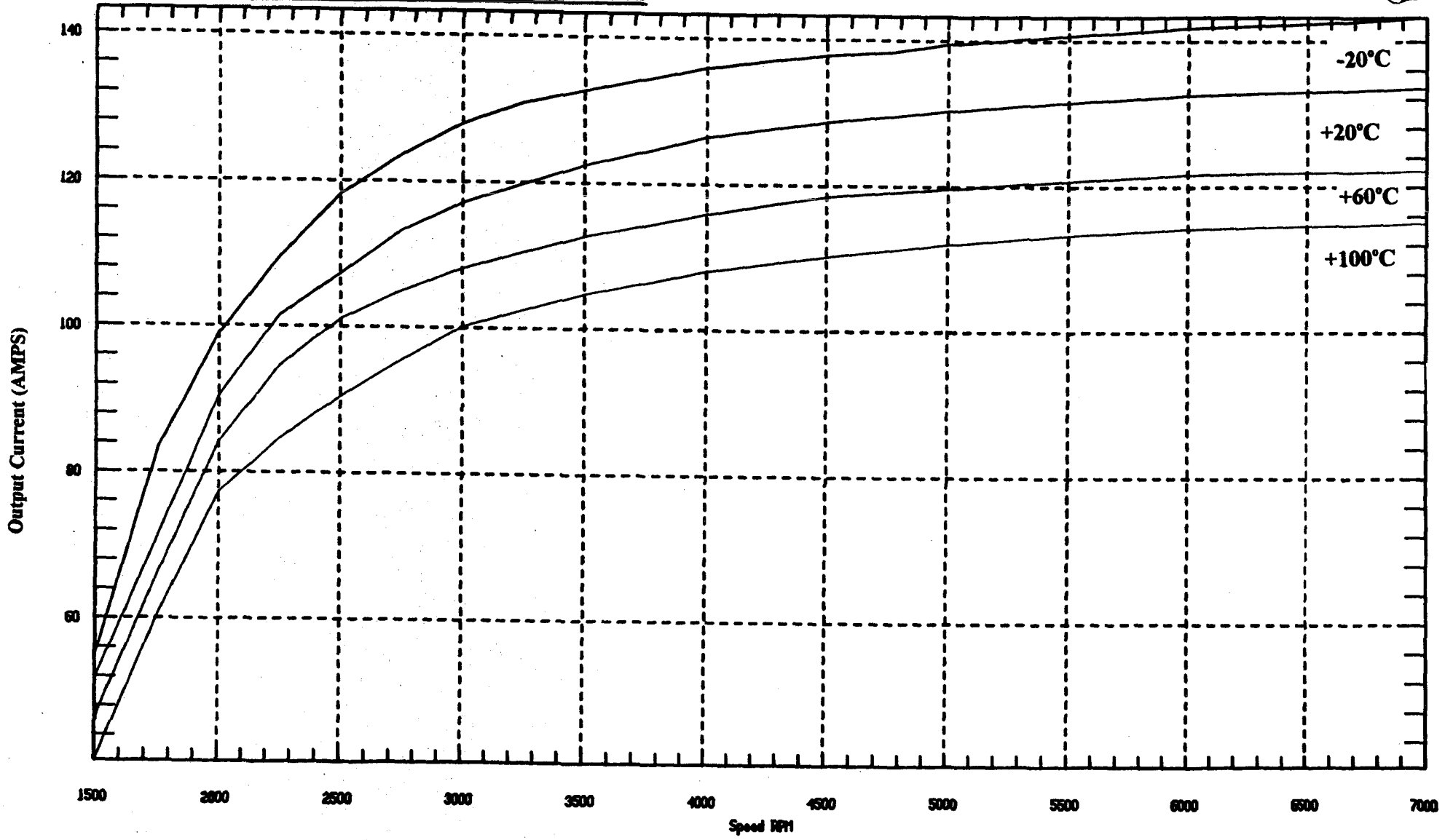
Therefore, as the alternator is better suited to automotive applications and is now almost universally used, only the use of an alternator coupled to the engine by a belt drive, giving a driven speed proportional to engine speed, will be considered here.

1. Engine Speed range. The alternator must supply electrical power throughout the engine speed range. Typical alternator output characteristic curves are shown in Figure 1 and demonstrate that the output varies significantly at the lower third of its speed range but will hardly increase at all up until a typical maximum continuous speed of 18,000 RPM. Therefore, the alternator must have a drive ratio that ensures its speed does not fall too low whilst also ensuring that it will not be driven to destruction.

2. Alternator Drive. This determines the maximum allowable drive ratio for the alternator and depends upon the type of drive belt, the number of other components using the same belt, power absorption of all the driven components, engine transient speed characteristics, environmental conditions and the required belt life.

FIGURE 1

CHANGE IN ALTERNATOR OUTPUT CURRENT WITH SPEED AND TEMPERATURE



L3BHE120 Ambient = -20degC-AMPS 54.9:143.3
L3BHE60 Ambient = +60degC-AMPS 46.4:122.2

L3BHE20 Ambient = +20degC-AMPS 51.6:133.5
L3BHE100 Ambient = +100degC-AMPS 40.5:115

5/3

3. Vehicle Electrical System. This encompasses the electrical sub-systems fitted to the vehicle and their power consumption requirements, the nominal system voltage, the type of wiring used for the main power feeds, and the type of battery used. It provides a complex set of requirements to be satisfied and provides one of the main challenges for charging system engineers.

4. Environment. The position on the engine where the alternator is sited, the layout of the engine bay and even the styling of the car can have significant effect upon alternator performance and durability.

5. Vehicle Effects. The alternator creates noise which increases with speed as well as drawing increased power with reduced efficiency. Therefore, it is necessary to have the lowest possible alternator speed whilst still providing the required electrical power to support the vehicle.

All the above requirements must be considered when designing a charging system, in addition to keeping the weight as low as possible and ensuring that the resultant system cost is justifiable.

In order to improve reliability, engine designs are often now fixed before the vehicles in which they are intended to be used are even designed. Therefore, it is necessary to make correct and optimal sizing decisions for the charging system as early as possible. The following text describes the tools and methods which Jaguar utilise to achieve this and how the system is proved out and continually modified until the vehicle project reaches production.

3. SIMULATION

Simulation is normally considered to be entirely computer based with the charging system being modelled mathematically. Unfortunately, an accurate mathematical model has yet to be created which can be applied to all types of lead-acid battery. Because of this, computer based models tend to be of limited use due to their inaccurate and rather generalised predictions which can lead to a lack of confidence in the charging system sizing decisions until actual vehicles are tested. Jaguar does use a computer model as part of the charging system sizing process but the main simulation process is performed using a test rig which uses real alternators and batteries, configured and loaded to the same conditions as a vehicle, in order to provide the necessary confidence to commit to specific components very early during a vehicle project. This section is split into two parts in order to separately discuss both areas of the simulation process.

3a. Computer Based Simulation

The charging system is relatively easy to simulate when under steady state conditions, such as a constant speed at a constant temperature with a fully charged battery. This is because when the vehicle has reached such a condition, the electrical system load will usually have also reached a steady state. Therefore, the charging system performance under such conditions is a simple mathematical operation where the maximum alternator output current is obtained from examining its output characteristics and then the total vehicle load current is subtracted from it. This form of simulation is ideally suited to computer modelling techniques.

However, the majority of a vehicles life is likely to be spent under more dynamic conditions with the temperatures, load current and vehicle speed all varying and the battery is therefore likely to experience constant energy throughput of either a charge or discharge nature. This is much more difficult to model accurately as it requires having an accurate mathematical model of the components under dynamic conditions .

The usual form of charging system simulation calculates the average vehicle load current over a particular test cycle and subtracts it from the average alternator output current. The alternator current is calculated by inputting the average engine speed for the test cycle and multiplying it by the proposed drive ratio to obtain the alternator speed. This value is then used to obtain the alternator current from its output characteristics, (which are usually provided by the alternator supplier), for a particular temperature . This process has the following benefits:-

- Different types of alternator can be quickly assessed.
- The effect of varying parameters such as engine speed, load current duty cycles or alternator drive ratio can be assessed.

Unfortunately, the process also has the following weaknesses:-

- Manufacturers alternator output characteristics never truly reflect the conditions experienced in a vehicle. This is because they are measured for constant temperature conditions. The temperatures seen on a vehicle are continually varying so the alternator output current for a vehicle under test may be significantly different from that predicted by using the suppliers performance characteristics.

• The battery performance is effectively ignored. It is usually assumed that if the end result of the simulation is positive, then the battery will be charged, which assumes that the battery will accept whatever excess current that the alternator can provide. However, in reality this depends on a number of factors which are difficult to simulate or which cannot be modelled, such as system voltage drop, battery voltage and battery charge acceptance capability. Any of these factors can lead to an ineffectual or inefficient charging system despite a promising simulation result.

The simulation program used by Jaguar adopts a different approach as, instead of averaging the data, it runs a 'pseudo real time' simulation of charging system tests. It was written entirely in house and is an event driven simulation.

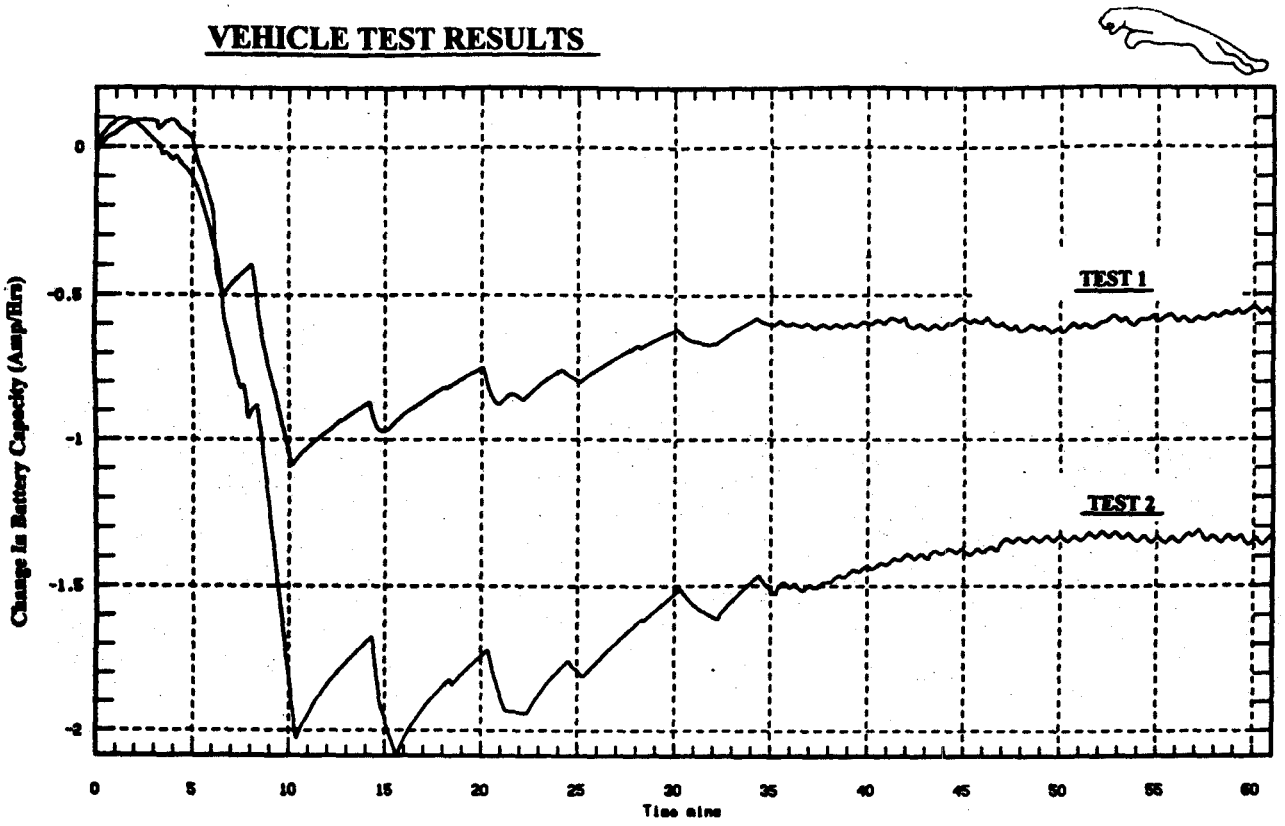
The user may program in a test cycle in the form of a time series of events. Events are identified by time and can be as close together as required but the time elapsed between events does not have to remain constant. The parameters used are assumed to remain constant between events so the number of events used for a simulated test significantly affects the accuracy of the result. At each 'event', a number of parameters, such as alternator and battery temperature, engine speed and whatever electrical consumers are operating, are set. The electrical consumers are chosen from a separate file which already contains the values of load current so, once a particular file of electrical loads has been chosen from a database, the user has only to be concerned with which consumers are switched on. Not every parameter must be set when an event is entered as, if any parameter is not set, then it is automatically assumed to have remained at the same state or value as the previous event in time. In this way, a detailed test cycle can be relatively easily programmed.

When a test simulation is performed, the user selects previously programmed test cycle, and alternator output characteristic files and then sets various factors such as alternator drive ratio, various special EMS based functions, battery size, battery state of charge and battery efficiency. The simulation then steps through every event in the test cycle in time sequence and calculates alternator, electrical load and battery current and battery state of charge, (based upon continuous integration of the battery current in conjunction with set efficiency factors).

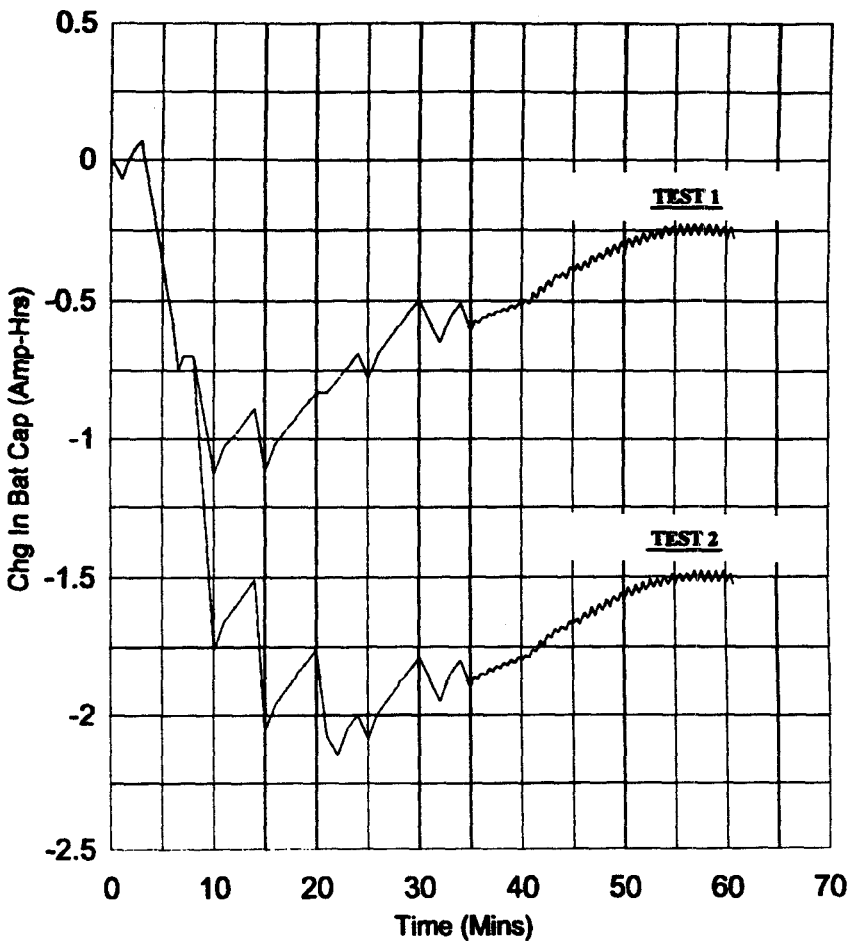
The resultant output file provides the computed and set values for each event and is stored on disk. It can be printed out to the screen or a printer in tabular form and can also be imported into a spreadsheet program to allow analysis of the test. Data from actual vehicle tests has been input into the simulation program to determine how accurate the simulation can be and a typical output from the simulation program is shown in Figure 2 against the result of the actual tests that were used as a source of input data.

FIGURE 2 - COMPUTER SIMULATION PERFORMANCE WHEN USING REAL VEHICLE TEST DATA AS INPUT DATA

VEHICLE TEST RESULTS



SIMULATION PROGRAM RESULTS



In addition to the advantages given for the averaging approach to charging system simulation, this event driven simulation program provides the following further advantage:-

- It allows a continuous trend of currents and state of charge to be assessed which helps the engineer to pin-point particular sections of the test cycle where the performance is likely to be unsatisfactory. This reduces the amount of simulations that are required to ascertain charging system performance as recursive simulations quickly allow the engineer to isolate factors that need to be examined in more detail and eliminate those of little interest. By contrast, the averaging process merely provides average values for the entire test and gives no indication to the engineer of where improvements may be made which then requires the engineer to 'guess' what to try next in order to improve system performance. Also, by using average values the engineer will only know that a result is either good or bad and will not be able to assess if the chosen components provide optimal performance, (ie assessment of alternator capacity utilisation for example). By examining the graphical trends obtained from the Jaguar program, the user can more easily identify if further improvements can be made and what combination of changes may have a significant effect.

Unfortunately, the Jaguar simulation does suffer from the following limitations:-

- The battery performance is simulated using factors obtained empirically from numerous tests. This method still suffers from accuracy limitations and can only be used as a guide to charging performance.
- The effect of system voltage cannot be assessed which means that voltage regulator settings cannot be assessed and the simulation therefore suffers further errors as, even though the electrical load current will vary with voltage, it is assumed to be constant for the simulation program.
- The alternator characteristic file uses a single output characteristic and a degradation factor of -A/°C to simulate the effect of temperature. This provides further errors as the alternator output reduction with increasing temperature is, in fact, non-linear. This could be improved by using a number of output characteristics for different temperatures but, given the above battery limitations and the fact that Jaguar has a simulation rig which uses real components, it is not considered to be worth the extra effort to include the feature.

For the XK8, (and subsequent models), this 'event driven' computer simulation program has been used to determine which alternator is worth testing and to provide the most likely optimal drive ratio and idle speed combination. It also provided an initial indication of where problems were likely to occur and which areas were likely to require more detailed investigation. This saved time and effort as testing a large number of alternators and drive ratio combinations using the test rig can be prohibitive in terms of the resource required to support the tests and the time taken to complete them.

For the XK8, a total of 15 alternators from 6 possible suppliers were assessed by using this simulation program. The results allowed the number of alternators actually tested to be reduced to 6 machines from 4 suppliers. These remaining prospective suppliers were then required to supply actual component samples for rig testing.

3b. Charging System Simulation Rig.

A schematic of the Jaguar charging system simulation rig is shown in Figure 3. It consists of two environmental chambers containing up to two alternators in one chamber and up to two batteries in the other. The components are connected with cabling that is as close to the real vehicle wiring harness as possible and electrical system load is provided by two variable load banks. The individual components can be interconnected or run as two separate systems. The alternators are driven through a geared drive by a motor controlled by an inverter drive and the batteries sit upon a tray which can be rocked to simulate vehicle motion. There is also the facility to simulate the effect of air movement around the components if required. The entire rig is controlled by a Programmable Logic Controller which is sited in the main control cabinet along with digital displays for the measured component parameters. The controller allows different test cycles, stored on floppy disk, to be loaded when required and the measured test data is stored on a PC via a serial communication link.

When the remaining prospective suppliers for the XK8 provided samples of the requested alternators, they were all subjected to the same batch of tests as follows:-

a. Output current characteristic measurement throughout the entire temperature range.

b. Voltage regulator performance throughout the entire temperature and load current range.

c. Simulated vehicle test cycles as part of a charging system.

These tests allowed the manufacturers claims for the alternators to be checked throughout their entire operational range as well as determining their performance when operating in a dynamic test cycle with a real battery. The use of the test rig also allayed supplier concerns about any anomalies in comparing data from different manufacturers as all the components were tested by Jaguar engineers under identical conditions.

The result of this initial batch of tests was as follows:-

- The optimal alternator and drive ratio combination was chosen before a prototype vehicle was built.
- Initial data was obtained about the likely performance of the XK8 charging system and, based upon this data, a further rig test program was initiated to further investigate areas that could possibly be improved.
- All XK8 vehicle tests, when performed much later in the project, used the same alternator and drive ratio. This meant that the tests were used for optimising the vehicle charging system and not attempting to choose the correct alternator and drive ratio.

CIRCUIT DIAGRAM

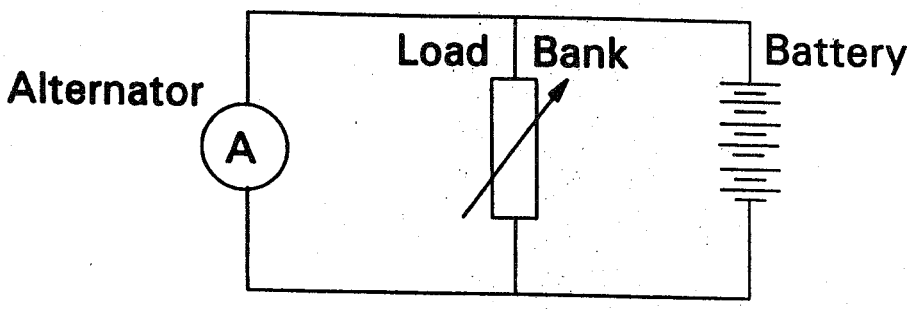
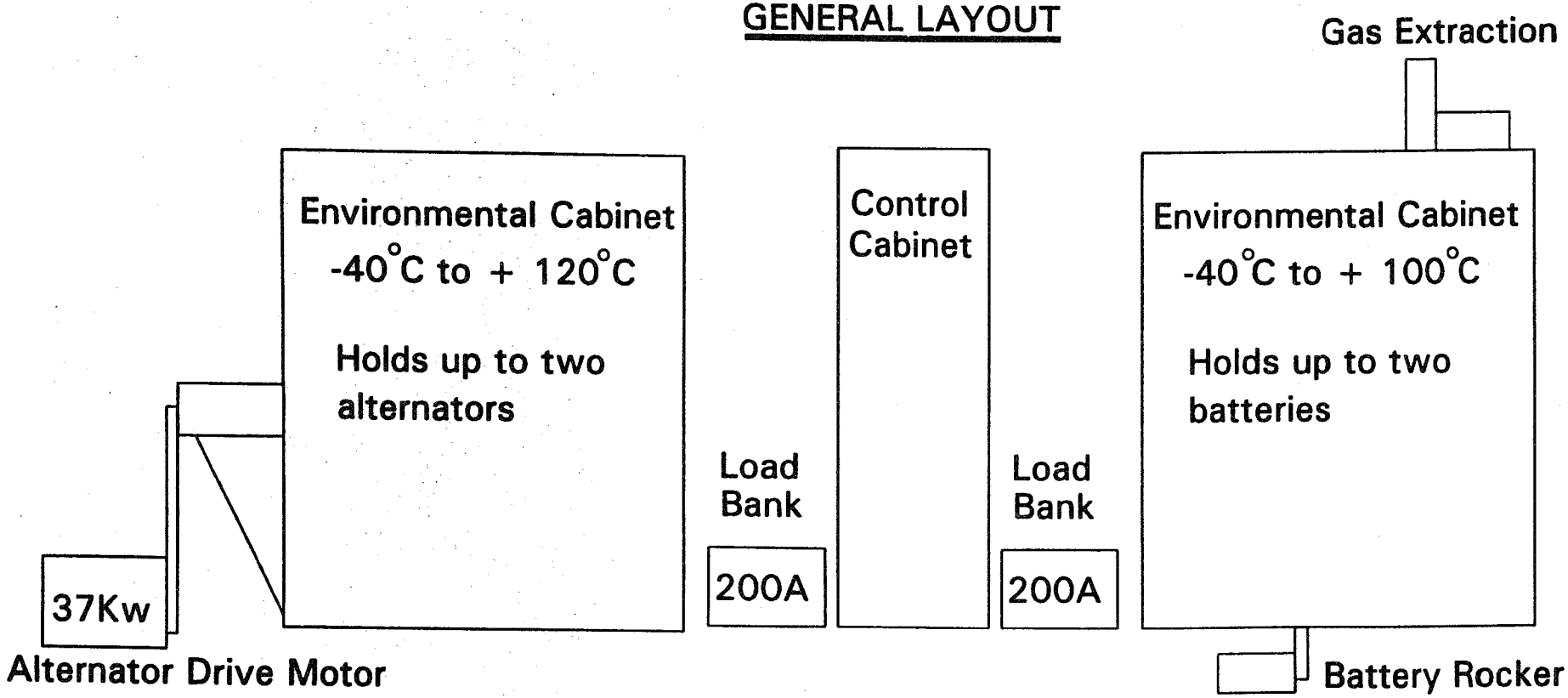


FIGURE 3

CHARGING SYSTEM TEST RIG

GENERAL LAYOUT



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As the XK8 project progressed, the electrical features fitted to the vehicle constantly changed. This is usually a source of great concern and uncertainty for charging system engineers owing to the limited accuracy of most computer based simulation programs which means that the actual effect of adding a particular feature is unable to be satisfactorily assessed until a vehicle is tested. This either results in reduced efficiency due to increased alternator size, (owing to engineers conservatism when under pressure to make a quick decision without all the relevant facts), or increased project costs in order to perform a test a in a climatic chamber which was not originally allowed for in the project plan.

However, for the XK8, provided that the load current and the functionality of the extra feature was known, then the effect on the charging system was determined by programming the feature into the rig test cycles and performing rig tests. As a result, Jaguar charging systems engineers are now able to provide a response on the effect of increased electrical feature within three days of the request being made, (dependant upon the level of re-programming required and whether the components fitted need to be changed), and this would be shorter if it was not physically limited by the time required to prepare the test batteries and normalise the components to the test temperature.

This provided a benefit to the XK8 as a number of extra features were added which, while benefiting the customer, required more power than the charging system could provide under certain conditions. As a result of test rig simulations, the operational mode of such features was modified such that they could be used whilst ensuring that the charging system was not unacceptably loaded.

The simulation test rig also aided in optimising the charging system components still further. Figure 4 shows the difference in charging performance obtained by changing from the originally recommended voltage regulator type to another, apparently less optimal one. The test results proved that the voltage/temperature characteristic of the original regulator provided inferior charging system performance, for the XK8 application, than the apparently less optimal type. The eventual change was only in the order of tenths of volts but the effect was significant and improved system efficiency. The rig was also used to prove that this new regulator did not significantly increase battery electrolyte loss and would not, therefore, reduce battery life.

Figure 5 demonstrates the change in alternator electrical refinement that occurred based on rig test results. Due to the need to rectify the generated power from AC to DC using a diode rectifier pack, every alternator has a small amount of 'ripple' inherent in its DC output. The initial alternator output waveform, (shown in Figure 5a), was not particularly 'clean' and contained an undesirable ripple and harmonic content which could possibly interfere with the vehicle audio system. Therefore, a number of modifications were made to the alternator to achieve the waveform shown in Figure 5b which was much smoother and had much reduced harmonic content. However, these modifications also reduced the alternator output power capability so, in addition to the test rig being used to obtain the noise measurements, it was also used to confirm that the performance of the charging system remained acceptable.

Therefore, prior to XK8 prototype vehicles being tested, Jaguar charging system engineers were confident that the optimal charging system components had been chosen and that, if anything unexpected was found during vehicle testing, the recursive rig and vehicle test procedures that were in place would help to quickly solve any problems and maintain the charging system performance at an acceptable level.

FIGURE 4

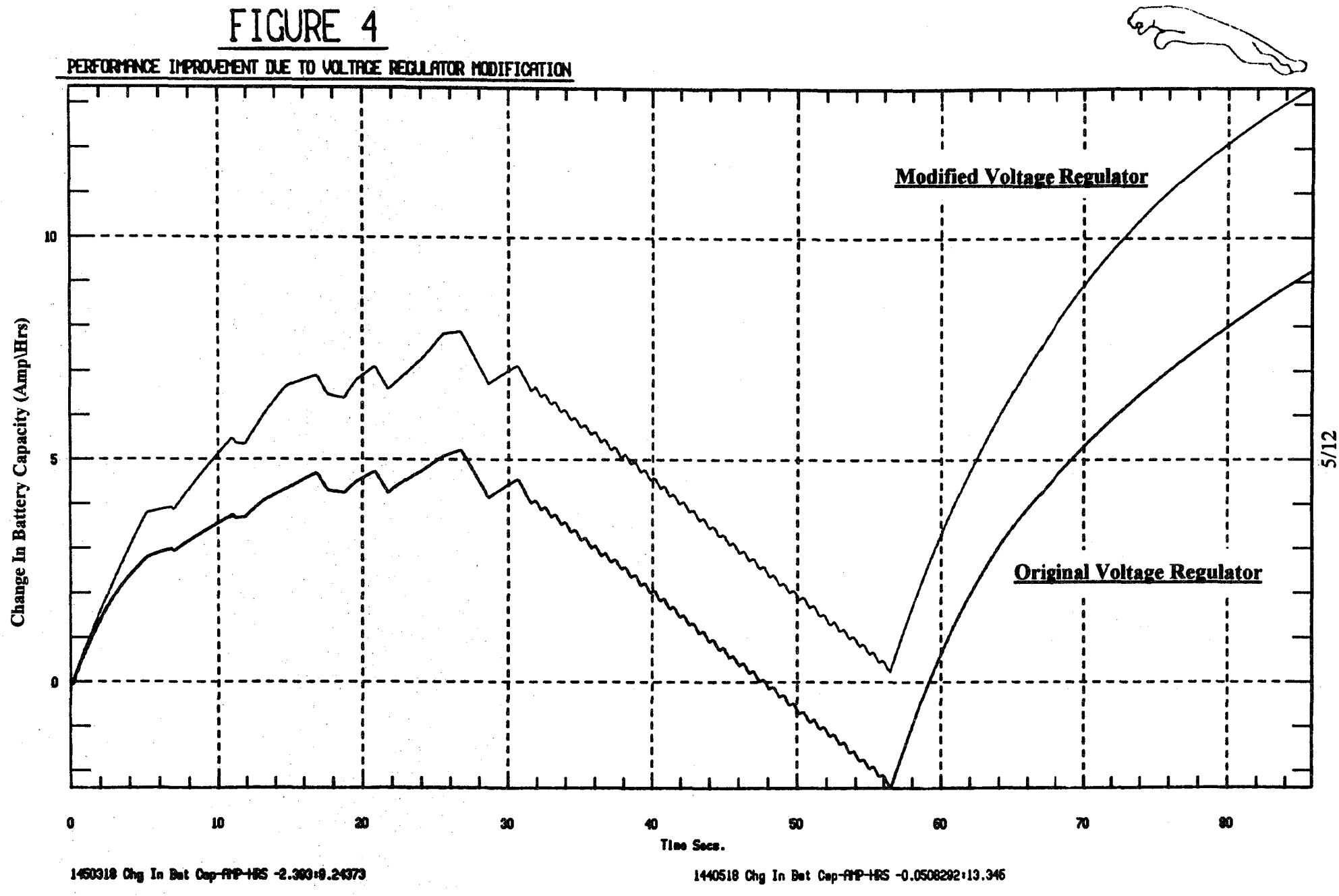
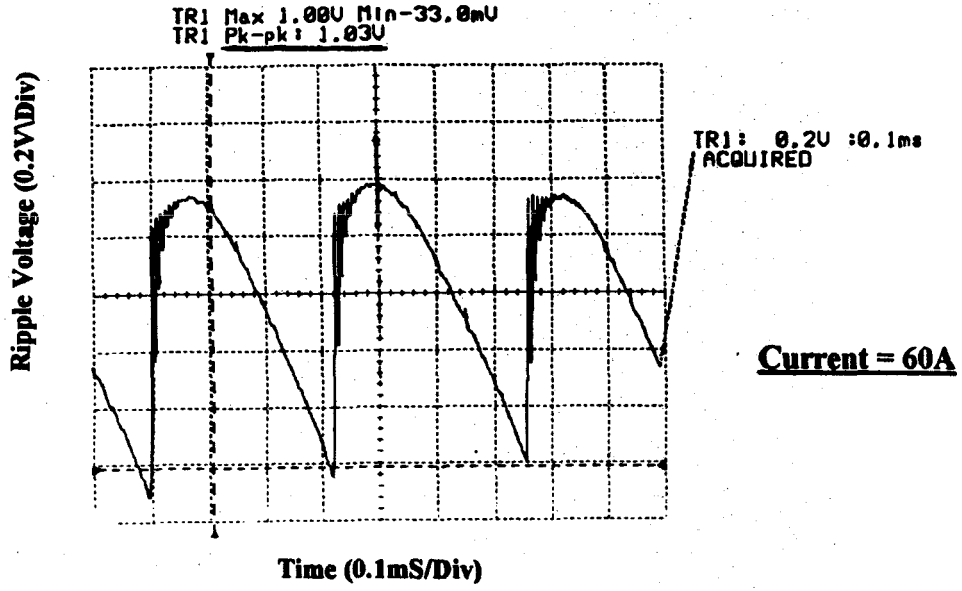


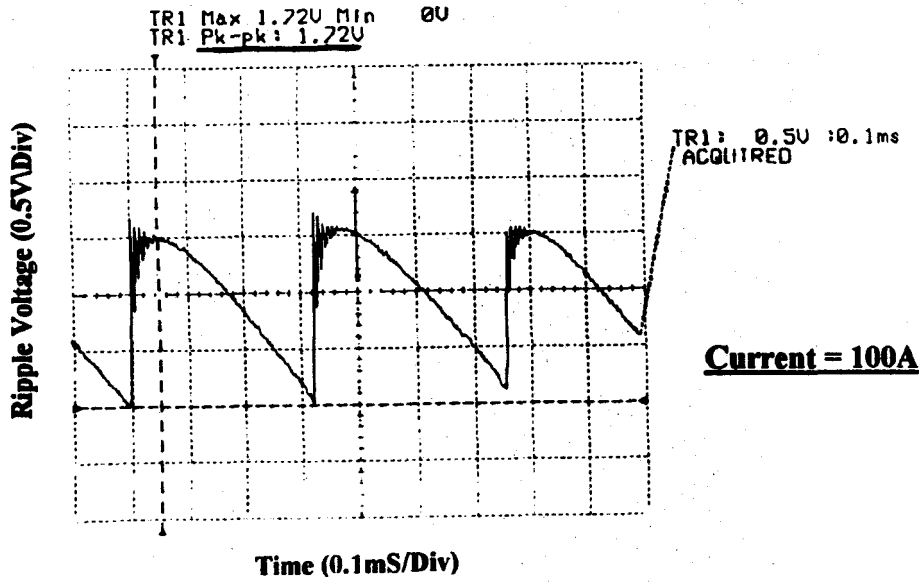
FIGURE 4

FIGURE 5 - IMPROVEMENT IN ELECTRICAL REFINEMENT

B - AFTER MODIFICATION

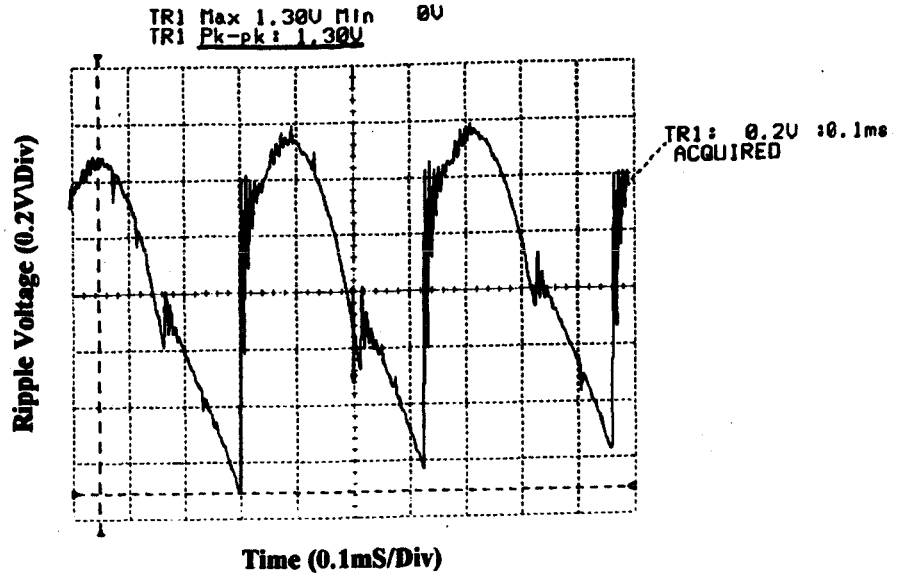


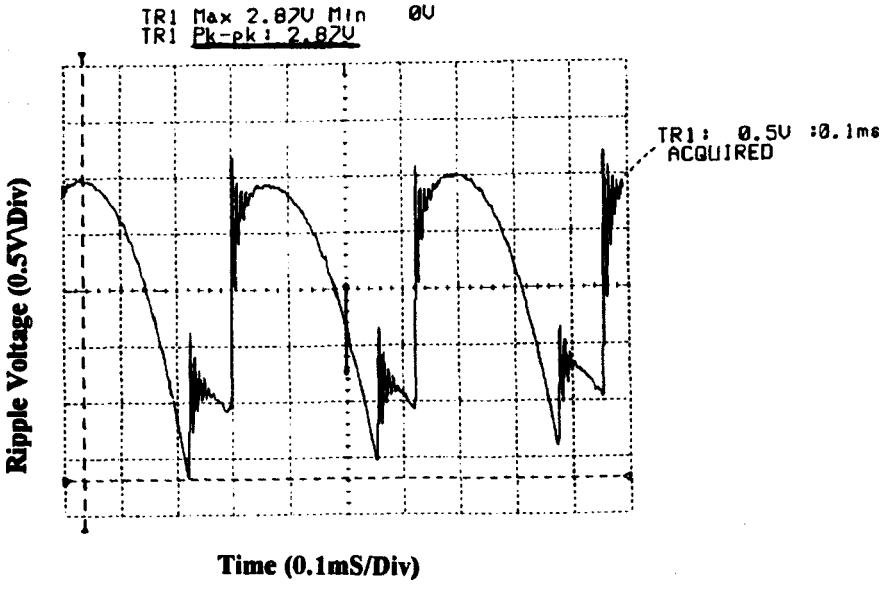
Current = 60A



Current = 100A

A - BEFORE MODIFICATION





4. VEHICLE TESTING

The early stages of simulation rig testing used the best available input data based upon tests of previous, different, vehicles and used calculated and estimated data from examining the intended component installations, the vehicle aerodynamics and its drive-train to estimate duty cycles. However, as such data was basically 'educated guesswork' charging system engineers started vehicle testing as early as possible in the XK8 project. At the earliest stage the vehicles used were 'simulators' which consisted of early versions of the XK8 powertrain fitted to XJS bodies so only data for component temperatures, engine speeds and very early indications of component duty cycles, was obtained. This data, though, was transferred back to the test rig to improve the accuracy of its results and improve confidence in the charging system.

Despite the use of the simulation rig, the charging system engineers still considered it necessary to test a significant number of prototype vehicles at each stage of the XK8 project. This was necessary in order to gather data, not only on charging system performance but also on the performance of other vehicle systems. As the charging system is almost the only system in the vehicle that is affected by every electrical or electro-mechanical system that is fitted, it is not sufficient to merely provide an alternator and battery that will support whatever the vehicle sub-system engineers demand. This would eventually lead to the electrical consumers going out of control to such an extent that there may not be an alternator powerful enough to support them. Therefore, it is necessary for charging systems engineers to examine the performance of as many sub-systems as possible in order to obtain data on their performance. This data and the personal experience of the engineers in driving the vehicles is then used as effectively as possible to allow more 'informed' discussions with the electrical sub-system engineers which then often leads to modifications being made which provide an acceptable compromise between the performance of the sub-system in question and its effect upon the charging system.

By following this process repeatedly, and in conjunction with increasingly accurate rig test simulations based upon the data fed back from the vehicle tests, it has been possible to fit more electrical consumers to the XK8 than was originally thought possible without having to use an unusually large alternator. In this way, the efficiency of the XK8 was aided by the charging systems sizing process.

Therefore, because of the use of the test rig early in the project, the XK8 prototype vehicle tests were used to enhance the charging system by attending to details such as aiding in calibrating the cooling and climate control systems as well as optimising the charging capability of the vehicle and setting up particular charging system related Engine Management System functions. At no time during the vehicle testing process was it necessary to test different alternators on the vehicle. Any changes to the components or additions to the feature content of the vehicle were simulated first using the test rig and vehicles were used simply to confirm that the rig test results were correct.

This recursive process of simulation rig and prototype vehicle testing continued up until the last prototypes built for sign off purposes. This was necessary in order to ensure that any changes to the vehicle that may have 'slipped by' the charging system engineers were detected when the vehicles were tested and, if the performance of the charging system was affected adversely, the cause was quickly identified and a plan put in place to recover the performance.

5. SUMMARY

The result of the process detailed here is that Jaguar charging systems engineers have more confidence than ever before in the performance of the charging system of a new model, despite the car having higher total electrical consumer demand than previous models and in addition to using a refined and low revving engine. Due to the efficiency of this process, Jaguar charging system engineers have been able to examine the performance of the XK8 charging system in depth over a much wider range of conditions than has previously been possible and believe that the best possible charging system has been provided within the constraints of the XK8 project.

This process has provided much improved traceability in the development of the charging system as every change has been documented with the reasons for such changes and their effects being detailed for future reference.

Work on the XK8 charging system effectively started during 1991 with the requirement to chose an alternator for the AJV8 engine and this process has been continually refined during that time with benefits passed onto other projects such as the 1995 model year XJ saloons. Consequently, whilst the process is continually being refined to improve efficiency, Jaguar are now in a position to develop a vehicle charging system in much greater detail than before whilst using less manpower to attain the results.

Therefore, whilst Jaguar charging system engineers are satisfied with the resultant charging system for the XK8, there are always areas that can be improved and our aim for the future is to ensure that Jaguar charging systems become more efficient and optimised than they are today by using the sizing process and design tools developed during the XK8 project.

THE XK8 BODY ELECTRONICS CONTROL SYSTEM

B.Ross & S.Savage.

Introduction

The XK8 being a new design gave the opportunity to introduce fresh concepts utilising the latest available technology whilst largely retaining the customer controls familiarity of the XJ saloon range.

The requirements of any program are to improve quality, minimise cost, weight and the number of parts/derivatives whilst maximising feature content and refinement. In addition the market is dictating that the development time of programs must become shorter to remain competitive. The production volumes for a luxury car are lower than other sectors of the market which means that the development costs are critical and opportunities to utilise existing developed technologies must be utilised.

Historically the increased feature content of cars has lead to an increase of hardware and wiring such that packaging space is now at a premium. This is particularly so in the case of Jaguar's cars, which being located in the luxury sector of the market, must fulfil the associated expectations.

The timing of the XK8 program meant Jaguar was able to take advantage of developments within its parent company, the Ford Motor Company. In particular, a multiplex control system developed specifically for automotive applications (Standard Corporate Protocol) and associated microprocessor based control modules.

These developments formed the basis of the XK8 body system to meet the above criteria i.e. to reduce wiring with the associated reduction in cost, weight and packaging space; refinement of feature operation and the flexibility to modify; reduced part count and associated production costs; and lower development costs.

What is a Body Electronic Control System ?

The body system can be loosely defined as non-driving functions operated by the driver or passengers. The functions controlled by the body system are :-

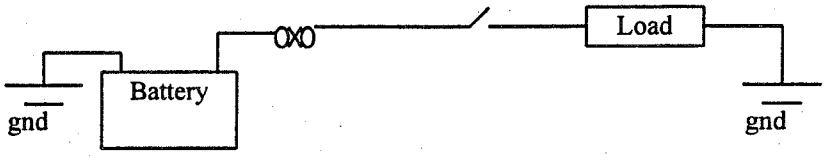
- Lighting (Interior and exterior);
- Wipers & washers including headlamp power-wash;
- Window control including entry/exit glass drop, one touch down window operation;
- Control of the Door Mirrors, Seats and Steering Column;
- Memorisation of two driving positions for the Door Mirrors, Seats and Steering Column;
- Locking, Security and Immobilisation;
- Convertible Hood operation; Warnings and Convenience features.

What is Meant by Multiplexing ?

Multiplexing is NOT a feature of the vehicle, but an enabling technology, the operation of which the car's users should not be aware of. Multiplexing allows microprocessor based modules to transfer complex information over a single communications link, comprised of one or two wires.

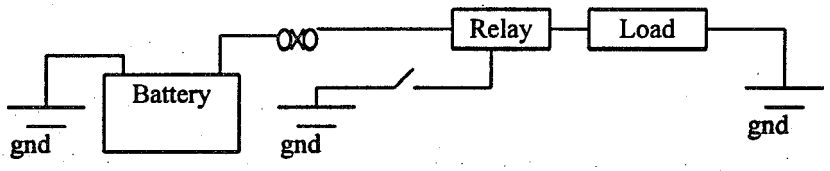
Over the last twenty years the approach to controlling electrical systems on cars has changed dramatically. The simplest form of control is for a switch to be in series with the load. The switch and harness wires then carry all the current required to operate the devise. This is known as High Current Switching.

Figure A: High Current Switching:



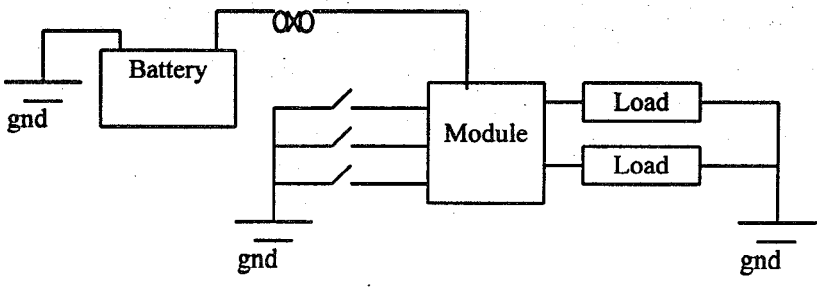
The first development was to Low Current Switching, where the switch operated a relay which sourced the current to operate the device, thus enabling smaller & less expensive switches to be used.

Figure B: Low Current Switching:



For more complicated systems requiring multiple switches & with multiple outputs, single chip microprocessor based modules were then used, with all the necessary switches and loads being hardwired to a single controlling module. This is known as Functional Partitioning.

Figure C: Low Current Switching via a Module:



The addition of a multiplexed link between these modules allows information to be shared whilst REDUCING the number of harness wires required (see figure F, later in paper). Once a switch or load is wired to one module, the status or control of that wire is available to all the other modules on the network via the multiplexed link.

An example of this is the Door Ajar Switch. On the XK8, this is hard wired to the module in the door. This Door Module broadcasts the state of the switch to the other modules on the link to control such features as interior lighting, instrument cluster door open warning, the security system and many other functions. The signal is used by nearly every module on the multiplexed link, but it is connected to only one!

The amount of information that can be transferred via a multiplexed link varies depending on the speed of the multiplexed bus or "protocol" used. A low speed system will operate at less than 10kbits/second, whilst the fastest real time systems can go up to around 1 Mega bit/second.

The XK8 Body System modules use the Ford Standard Corporate Protocol (SCP), which is a mid range system, operating at around 50 kbits/second. This translates to a maximum of 700 messages/second.

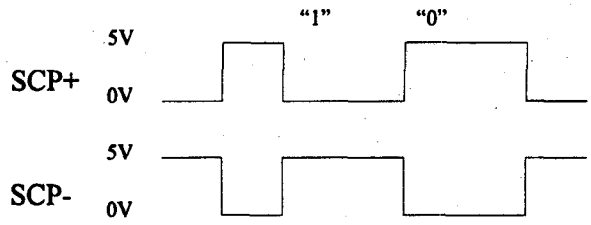
Ford's Standard Corporate Protocol (SCP)

The SCP complies with the requirements of the Society of Automotive Engineer's requirements for automotive multiplexed links, the SAE J1850 specification.

SCP uses TWO wires, twisted in to a pair. However, the system will operate fully with only a single wire intact. As shown in figure D, the SCP- line rests at five volts & is driven to ground, whilst the SCP+ line

rests at ground & is driven to five volts. These steps increase the robustness of the link whilst reducing the risk of radiated electro-magnetic emissions.

Figure D: SCP + & - Line Configuration



The link is used as a star network (see figure E). There is no controlling module, a system of non-destructive arbitration & message priorities is used to determine access to the bus. The format of these messages is pre-defined and is controlled by a standardised Ford world-wide data-base.

To avoid increasing the processing burden on the control modules own microprocessors, SCP adds a Hosted Bus Controller Chip (HBCC) to each module on the bus. The HBCC takes care of all the overheads of transmitting & receiving messages of the SCP network. The HBCC together with the SCP interface and termination components (which together make-up what is called the "Physical Layer") represent all the hardware additions necessary for a module to communicate via SCP.

For Body System applications messages are sent on an EVENT, such as a door being opened. With the robustness of the design preventing messages from being lost, the message is not repeated until the event occurs again. This reduces the number of messages sent, allowing the system to operate at it's lower bus speed. The exception to this are the critical messages, where periodic messages are used.

The XK8 SCP system does not exceed 20% bus loading, even during the busiest periods of normal operation.

With modules being permanently powered, action is necessary to reduce the load on the battery when the engine is not running & the ignition is off. To do this, any or all of the modules may enter a "sleep mode" during periods of inactivity. These sleep modes reduce the current drawn by the modules to as little as half a milliamp, which contributes to the vehicles requirement of a long term parking & starting capability.

The Body System Application to the XK8

The body system functions referred to are located or controlled in six areas, the two doors, the two front seats, the facia and boot. A module was allocated to each of these areas resulting in four module types being required i.e. Door Module, Seat Module, Body Processor Module (Facia) and Security & Locking Module (Boot). In comparison the XJS which was functionally less complex had eight modules and for example did not include windows or steering column control.

Microprocessor based modules were chosen to allow the flexibility of change, refinement of control and sophistication of functions desired. For the XK8 Jaguar implemented a program in conjunction with the Automotive Component Division of Ford who supplied the electronics.

Reference to figure E (below) shows the module locations and system interconnections.

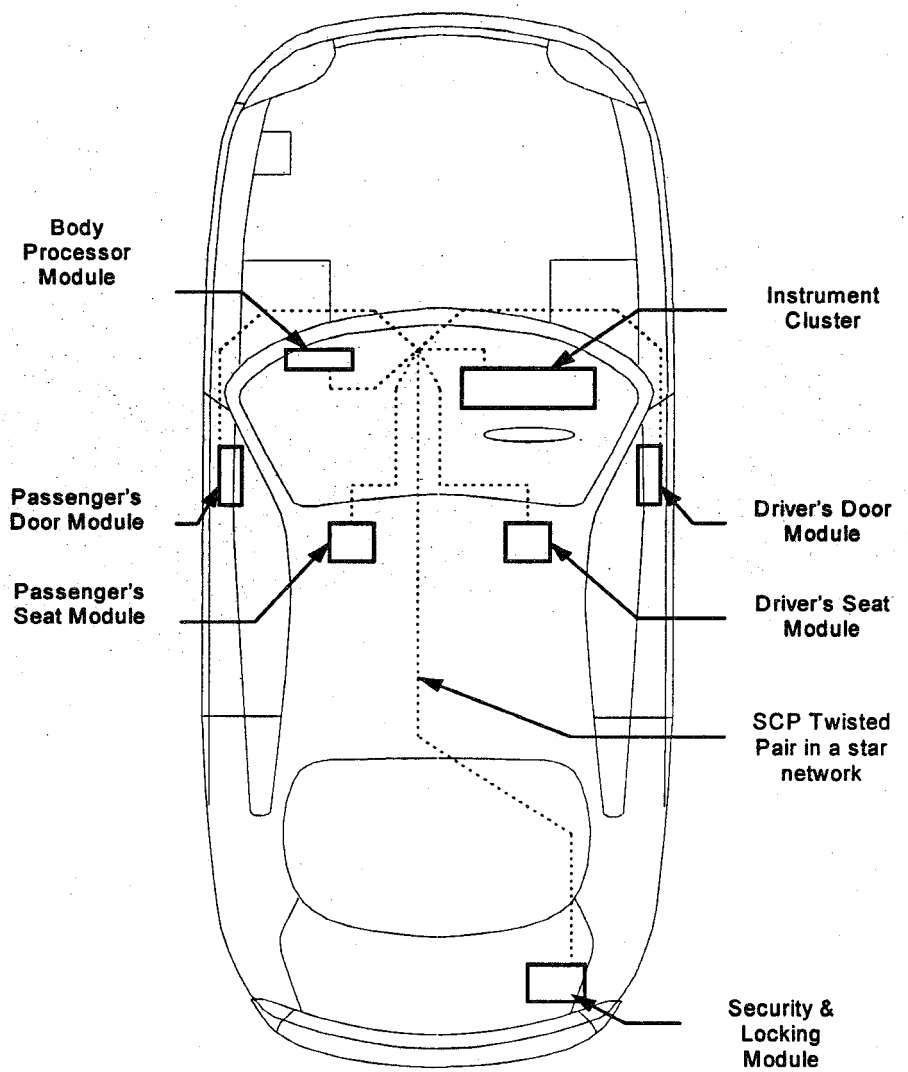


Figure E: Body System Module Location

In addition to the body system modules the SCP bus is also connected to the instrument cluster. The body system utilises the instrument cluster to obtain the status of the power train from the CAN networked information i.e. Gear Selector position, Engine running, Vehicle speed. The car has two other communication networks; the Controller Area Network (CAN) used for high speed communication within the power train system and an ISO 9141 data bus used for diagnostics communication to the small number of modules not on SCP or CAN (Ref. Appendix 1).

The Door, Seat and Security & Locking modules utilised an existing design with minor hardware changes and new software. The Body Processor module was a new unit developed especially for the XK8 but also to be utilised on the 98MY XJ saloon range and future programs. The requirement to minimise the number of part derivatives was satisfied by having only one variant of door, seat & body processor module and two variants of security and locking module. Model, market and feature level variants are controlled within the system software by end of build option programming on the production line. Driver and passenger side "identing" is carried via an "ident" connection for the seat module and by recognition of the number of window switches present for the door module. The security and locking module contains the remote control

receiver, due to there being two operating frequencies across the world markets two part derivatives were required.

The system is delivered programmed to a set of default parameters with the variables located in the EEPROM section of the microprocessor. At the completion of the build all vehicle systems are programmed against the vehicle specification, the body system options being part of this process; for example the security system variants, locking system variants, memory or non memory, daytime running lighting (Scandinavia & Canada), hand of drive and convertible or coupe model. Disabling or enabling of software controlled convenience features can be carried out at a Jaguar dealer to satisfy customers individual preferences, e.g. reverse mirror dipping, chirps and light flashing upon locking/unlocking/arming etc.

The first stage of the application was the writing of the feature functional specification that defined the system operating philosophy. From this the functions and system operation were animated using computer functional modelling techniques (Ilogics Statemate). The specification and models were then circulated for review and comment within the company. The models provided a visual appreciation of the functions over a year before any representative vehicles were available and in good time for change to be made before software production had started. The modelling technology at that time had limitations which resulted in more conventional techniques being used during the production of the control module software.

The zonal partitioning was then carried out. As we are dealing with a system, functions are not constrained to be located in one specific module. A function's input/outputs are taken to/from the nearest module and likewise the software control of a function can be in several modules for thrift of code and reduction of bus messages. Taking as an example the security sub-system, figures F & G demonstrate the input & output partitioning and software partitioning respectively.

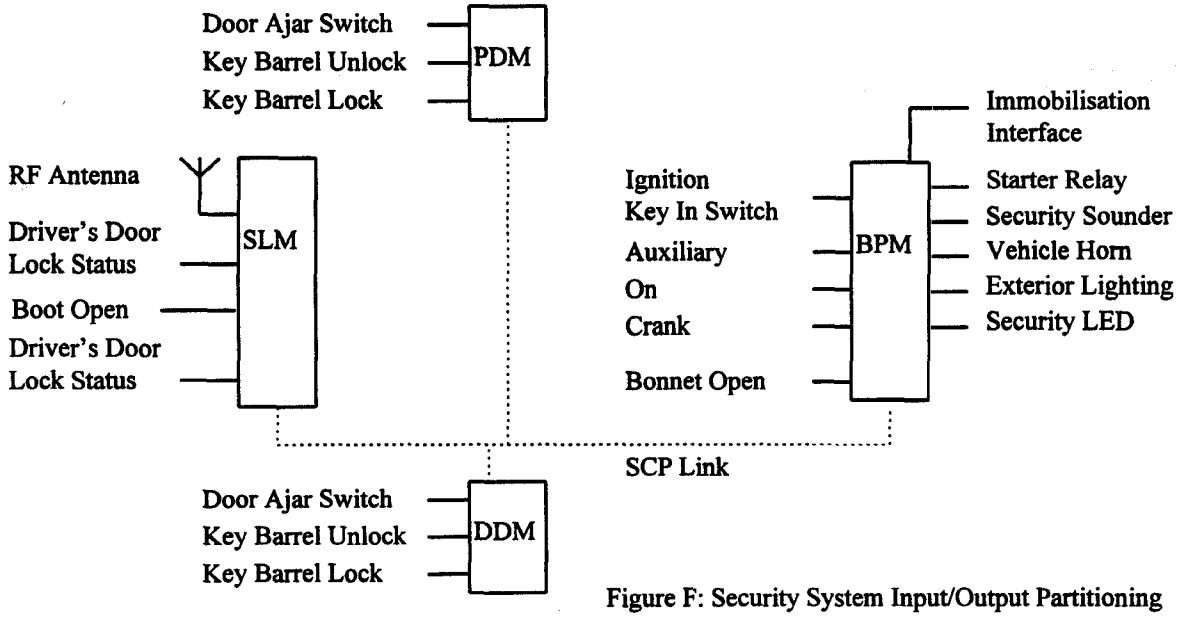
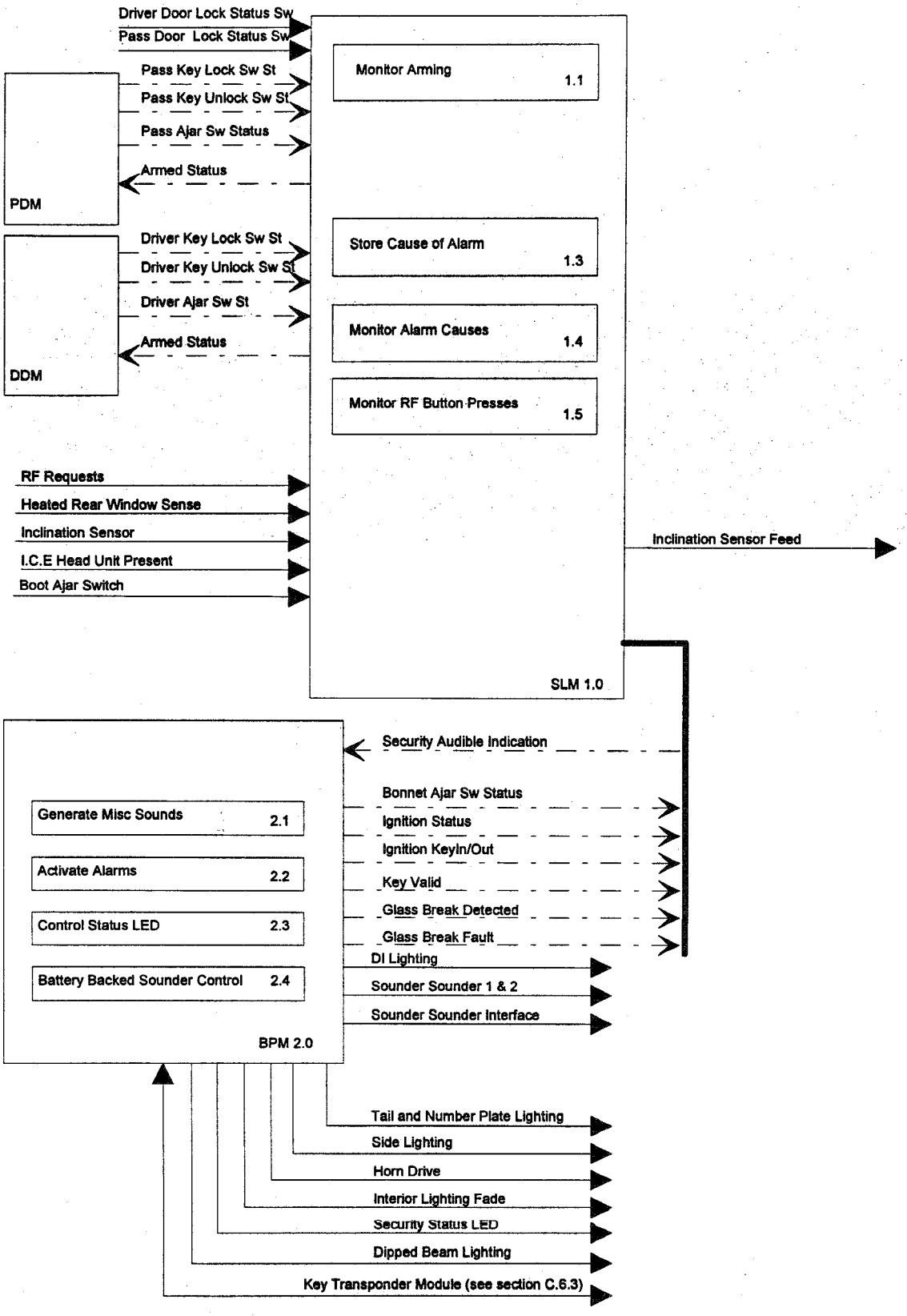


Figure F: Security System Input/Output Partitioning

A static buck (called the 'yellowboard') was constructed at Ford's premises for development and testing. This was a physical representation of the car on a yellow bench. The buck contained the body system and the associated vehicle components interfacing to the body system in approximately the representative car location and orientation i.e. harnessing and fuse boxes, lighting, seats components, door components, steering column components, facia components, instrument clusters etc. This was in parallel with the first stage of Jaguar prototype vehicles. Key areas of the buck were updated throughout the project as the rest of vehicle development progressed.

Figure G: Security System, Software Partitioning



Once vehicle hardware became available a continual process of evolution and testing was carried out. This continued from the early prototypes through to the pre-production builds. Functional, system, durability and "abuse" testing were carried out. In parallel, customer focused appraisals of functionality were also carried out.

The microprocessors used during these phases were One Time Programmable (OTP's) which allowed the flexibility of late software change, but incurred a higher piece price and availability penalties. The final stage was to freeze and release the software to proceed to a dedicated masked part with the resulting piece part reduction.

Examples of Sub-Systems Within the XK8 Body Control System

- Front Window Operation.

Entry and exit glass drop: As a door handle is operated with the window closed, the system automatically lowers the window a controlled amount to clear the door seals and closes the window upon door closure. This allows a seal profile to be used for minimum wind noise and increased in car comfort. The locking and security sub-systems have an input in that this does not take place if the car is locked or armed (i.e. door handle lifted whilst parked).

One touch window operation where by a momentary operation of the switch allows full downward travel. The next stage of refinement of the window position control, used during entry/exit, is the addition of one touch upward travel with the associated blockage sensing (anti-finger trap) and window reversal.

- Convertible Hood Control & Automatic Powered Latching

One of the major feature additions for the XK8 is the extension of the hood control sub-system to include the addition of automatic latching of the front edge of the convertible top to the top of the windscreen (the header rail).

The Security & Locking module, located in the boot near the hood pump & rear hydraulic rams, controls the movement of the soft top. This includes control of the header rail powered latching system, although in true multiplexed style, the header rail switches are all linked to the nearest module, that being the Body Processor module in the facia.

By a single maintained switch press, the driver first lowers the rear windows, then initiates the cycle that unlatches the hood and folds it away behind the rear seat. To protect the window seals, the cycle also lowers the front windows out of the way before moving the soft top.

To raise the hood, a single maintained press of the close switch reverses the process. The soft top is raised from it's stowed position and automatically latched to the header rail, before the rear windows are raised.

To make opening & closing the soft top even move convenient, these functions can also be operated by holding the door key barrel in the unlock or lock positions respectively.

- Vehicle Security & Immobilisation

The XK8 security & immobilisation sub-system is a development & refinement of the features offered by the award winning XJ6 saloon system, in which the multiplexed body system takes over from the functionally partitioned modules used on that vehicle.

The use of multiplexing to reduce the harness runs has been shown previously by figure F. Whilst the functional improvements include the increased encryption of the communications between the main immobilisation modules and the increased integration of the sub-system in to the electrical architecture of the vehicle.

Due to the need to cope with the convertible soft top, the ultrasonic intrusion sensing used on the saloon has been replaced by a new glass breakage sensor able to "hear" and identify the sound of the vehicles own glass being broken.

The overall vehicle security package has been approved by the Thatcham organisation, working for the ABI, and has achieved their "E" rating, as exceeding their requirements for a luxury car of this type.

The Benefits of the Multiplexed Body System to the XK8

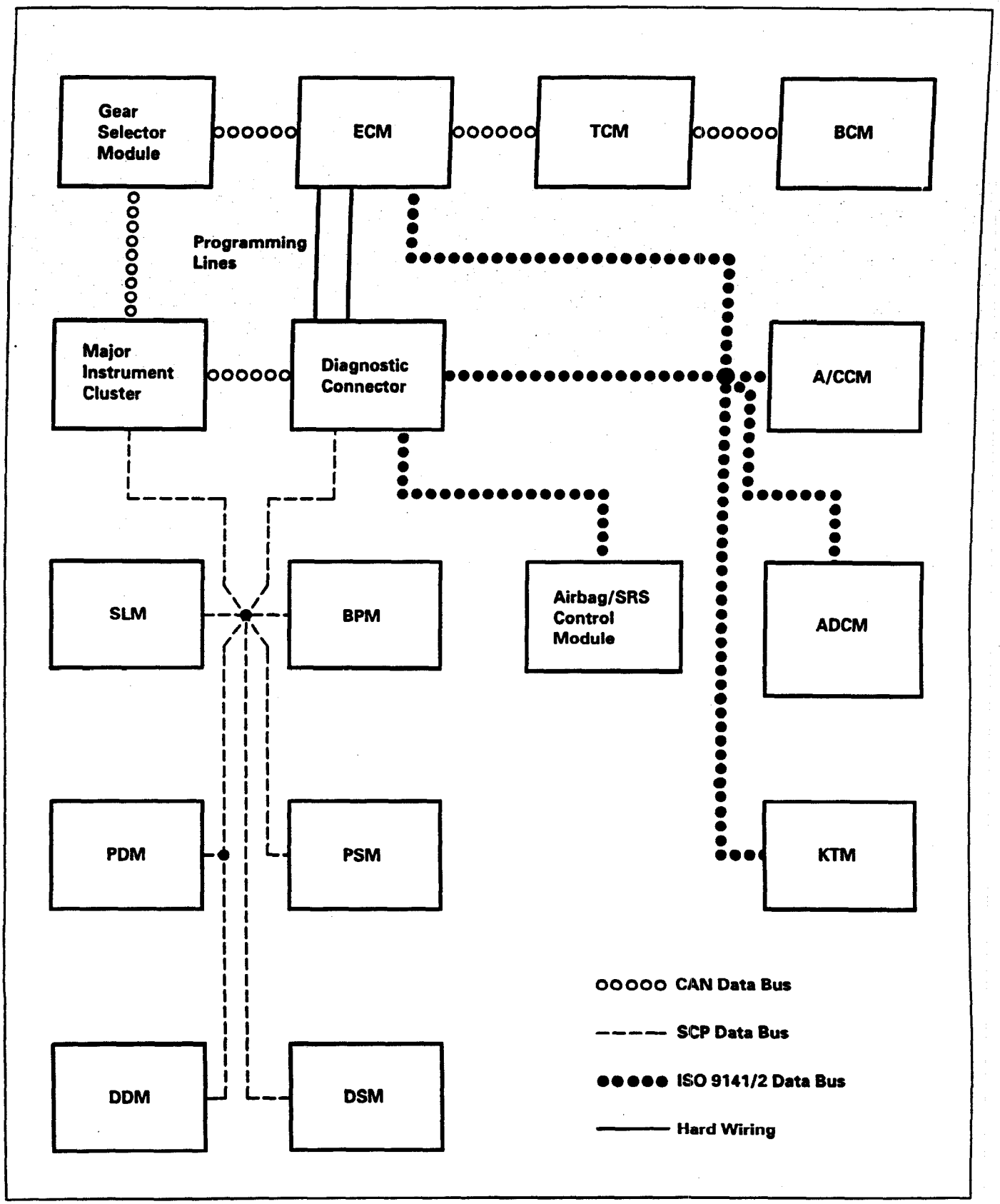
The following are some of the benefits that the XK8 programme has gained by using an SCP multiplexed Body System:

- Reduced wiring runs, where possible a switch or load is connected to it's nearest module AND only to that one module.
- This has allowed the adoption of modular harnessing, with the boot, cabin & facia having separate harnesses.
- Multiplexing has encouraged software control of functions, reducing the piece cost of adding features.
- Reduced number of modules AND variants of modules, able to support all world markets via the increased use of option programming during vehicle build.
- Increased flexibility in the design of functions, with all signals & loads being available for all the Body Systems functions. This promotes more sophisticated design.
- Increased use of smart switching of module outputs to reduce the number of fuses & relays required in the vehicle.
- Improved vehicle diagnostics, with the ability to monitor module inputs & outputs during normal vehicle operation ("flight recording") AND increased use of Diagnostic Trouble Codes to capture intermittent concerns.

When grouped together, these benefits have allowed the XK8 body control system to support the programmes objectives of reduced vehicle cost & weight and to make the vehicle easier to assemble, reducing build times whilst supporting the level of functionality required for a luxury car.

APPENDIX 1

XK8 COMMUNICATION NETWORKS



THE ARCHITECTURE AND ANALYSIS OF THE XK8 ELECTRICAL SYSTEM

C. Forde

1. Introduction

The Electrical Distribution System (EDS) is the network of wire, connectors, fuses and relays which carry the electrical power, signals and information around the car. It is the "backbone" and "nervous system" of the XK8.

The primary objectives in designing the new distribution system for the project were to reduce wiring, weight, packaging space, and complexity; improve ease of manufacture; reduce build time of vehicle; lower development costs; improve quality. Additionally produce production intent design and process significantly earlier during the development of the vehicle. This was achieved via system integration, increased system robustness and in just 36 months from programme approval.

We shall firstly describe the overall design approach, and then some of the details of the actual harness design.

2. The Design Approach

2.1. The Multiplex Option

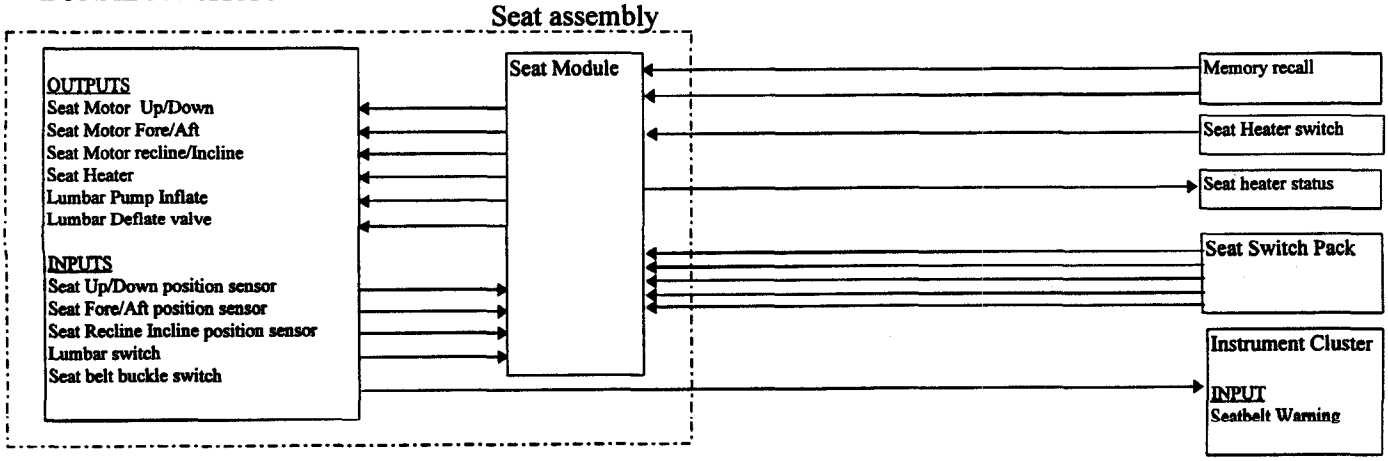
A primary decision involved using either traditional 'point-to-point' wiring, or a multiplex approach. Initial investigations showed that wiring and connector reduction using a multiplex system would offer advantages to manufacturing in terms of ease and speed of assembly, and the possibility of enhanced diagnostic capability. With this decision taken, attention could then be directed to the actual hardware architecture.

2.2. The Architecture

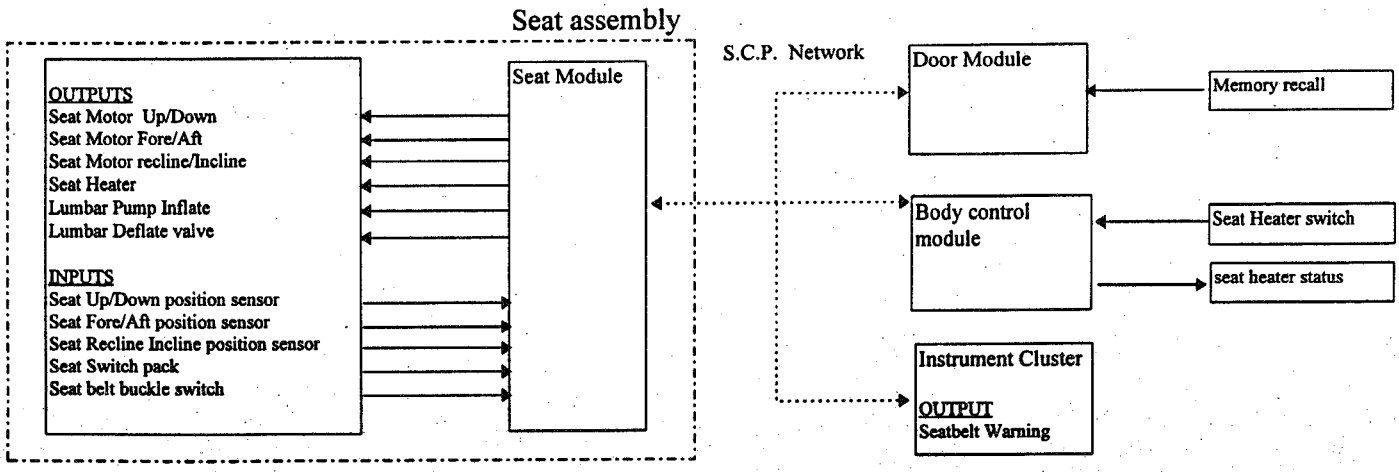
In this regard Jaguar has followed an evolutionary approach. The Jaguar distribution architecture used on the 1995 model XJ6 was quite advanced, in that much of the system integration had already been 'Zonally Partitioned' making it suitable for a communication network, where by functional partitioning of inputs and outputs could be applied. Some examples of functional partitioning are:

a) Control module located in seat assembly:

ZONAL PARTITIONED



FUNCTIONALLY PARTITIONED



Some other Applications of Functional Partitioning are:

- Separate door modules controlling door functionality.
- Separate boot module controlling rear functionality and security, plus convertible hood control.
- Separate Body module located in 'facia' for wipers, interior lighting, driver controls, and lighting

However some of the system functionality is shared across all modules via the S.C.P. Network , based upon location of input and output requirements..

Power Distribution

A major consideration is the treatment of the power cable. This is substantially influenced by the position of the battery, which is fitted in the rear of the vehicle. The reasons for this choice of position were:

- Protection to the battery in the event of a crash. Growth of battery physical size compounded this issue due to Key-off loads / stand time and increased electrical feature/ accessories. This required the battery to be located in the boot since packaging in the underbonnet area was likely to compromise the distinct Jaguar style.
- Increase in vehicle underbonnet temperatures, combined with improvements in charging performance, required the battery to be located in a lower ambient temperature to prevent the battery 'boiling'. The increase in underbonnet temperature is a result of increased engine performance, and the use of close-coupled catalytic converters mounted directly to the exhaust manifold. Again an increase in cooling performance of the underbonnet area was likely to compromise the distinct Jaguar style of the XK8.

The disadvantages of this choice of position is that the alternator becomes a sizeable noise source to many of vehicle electrical systems, both through the circuitry (AC-ripple) and through radiation. To assist in reducing the noise generated by the charging system, a dedicated cable has been used to combine both charging and starting.

More generally, the wiring was designed to give maximum separation between noisy circuits 'sources', and potential sensitive circuits 'receptors'. This was achieved by locating sensitive signals and low current signals in a separate harness. The noise signals were located in another harness and routed to provide separation of the harnesses in the vehicle. The wiring has also been routed to avoid in potential sensitive areas e.g. near the In-Car Entertainment components. This has improved the immunity of the vehicle to electromagnetic coupling.

2.3. Systems Approach

The traditional approach to electrical design has tended to concentrate on individual components, and to try to infer overall system performance on the basis of correctly performing individual components. While the approach is not without its merits, it ignores the fact that the whole system has to perform correctly, i.e. the interactive effects between components and modules. The approach which Jaguar has adopted is referred to in-house as a 'Circuit-Led' approach. In this approach the desired functionality is traced to the electrical circuit that is required to deliver it. This circuit defines the 'system', i.e. the collection of components in a given circuit. The approach therefore naturally focuses on critical issues such as required component input/output conditions, interface criteria, noise creation and immunity, and in general environmental requirements.

The design of the system / circuit consists of two parts, design rules and circuit analysis..

a) The Design Rules are mainly codified experience, e.g.

> The steady state load current through a standard automotive fuse should not exceed 70% of the fuse rating. $I_L \leq I_N * 0.7$
>
> Where:
>
> I_L = Total Load current.
> I_N = Fuse Rating.

This rule has been based on a number of factors that could influence the fuse under continuos running conditions: ambient temperature, fuse interface, area of connecting cable, temperature rise of connector and cable, due to ohmic dissipation.

b) Circuit analysis is traditional, i.e. essentially an Ohm's law analysis, though to this has been added signal analysis, such as:

- Short Circuit Analysis - for fuse blow time
- Voltage Survey - full interaction via ground and fuse trees
- Load Survey - determines current through each fuse.
- Sneak Analysis - uncovers potential unwanted current paths (logical).
- Signal Analysis - electrical sensitivity and characterisation.
- Branch Analysis - fuse and ground trees connectivity (logical).

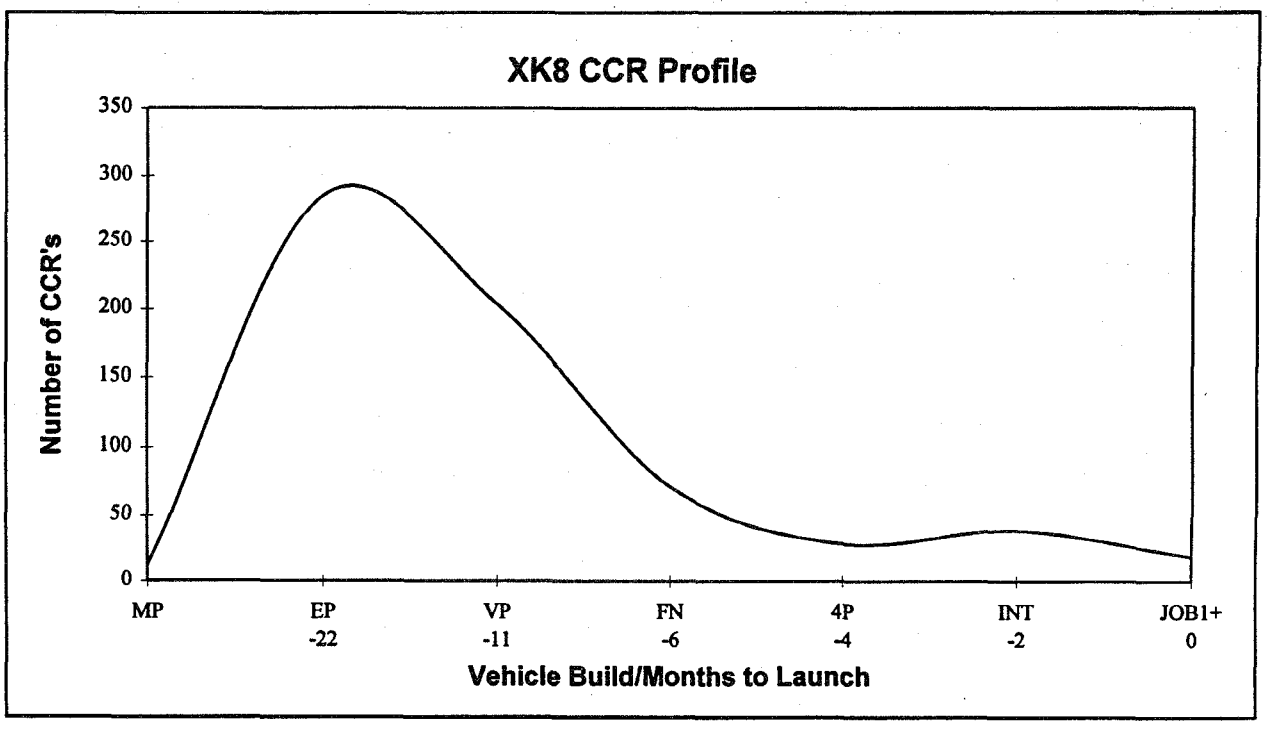
The circuit analysis activity has been greatly assisted by linking the CAD harness design and the analysis environment. This process has been under development in Jaguar for about ten years. A number of process simplifications of component behaviour are used in the development of a circuit model. This procedure is well-justified in terms of resource and time. Accurate / detailed component modelling is labour intensive and it is often the case that the component design will change significantly during the course of development, and sometimes it may even be deleted. In addition to these simulation techniques, there a number of cases where more sophisticated tools are used, e.g.

- Transient Analysis - Real time signal response.
- Sensitivity Analysis - measure of design performance, in relation to variables/ system parameters.
- Stress Analysis - measured value of a component considering de-rating and specified rating.
- Characterisation - Simplified component model for design rule checking..

The point we wish to bring out here, is that traditional circuit modelling allows the design of harness elements such as fuses, relays and of course the harness cable itself, to be incorporated into the system performance assessment. Overall, the combination of design rules and circuit analysis has had a substantially beneficial effect upon the development of the total electrical system. With the system circuits well understood, provided components are to specification and assembly in the vehicle is correct, then development testing is more effective. Fewer cars are needed to test vehicle variants, and the traditional problem of test data appearing from one build phase simultaneously with the need to specify the 'new improved' components for the next phase is substantially overcome. Indeed, the typical traditional situation of many late changes arising from a belated understanding of component tolerances, and susceptibility to sneak circuits is greatly improved. Additionally with a stable wiring design base, the validation of the complex software driving the multiplex system can concentrate on function rather than having to cope simultaneously with the physical circuitry.

Did the approach work ?

A good measure of success or otherwise, is the time-profile of the 'Circuit Change Requests' (CCR's) in the months prior to the Job 1. The accompanying figure shows very clearly that the majority of changes occurred in early prototype phases and thereafter declined rapidly. There was however a slight increase in a late build phase due to an accumulation of actual driving experience with a larger number of pre-production cars, cost reduction activity and the experience of building cars in increasing volume.



Note: CCR freeze date was approximately 4 months prior to Build date. Build dates are shown. For example: start of FN Build date is -6 months, CCR cut off date would be -10 months.

3. The Distribution Design

3.1. The Power Cable Architecture

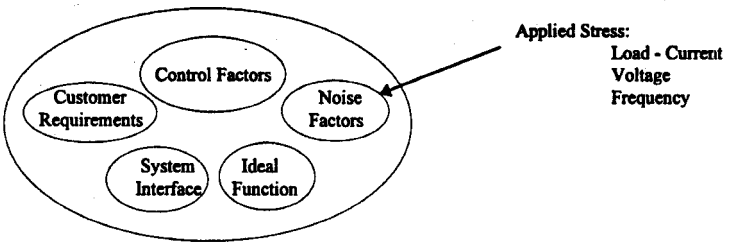
The XK8 benefited from the use of the power cable architecture as previously applied to the Jaguar XJ6 saloon model introduced in 1994. Since relocation of the battery into the rear of the vehicle the electrical noise generated by the alternator has become a considerable electrical noise source to many of the vehicles electrical systems, and in particular the audio circuit, previously identified as a customer concern.

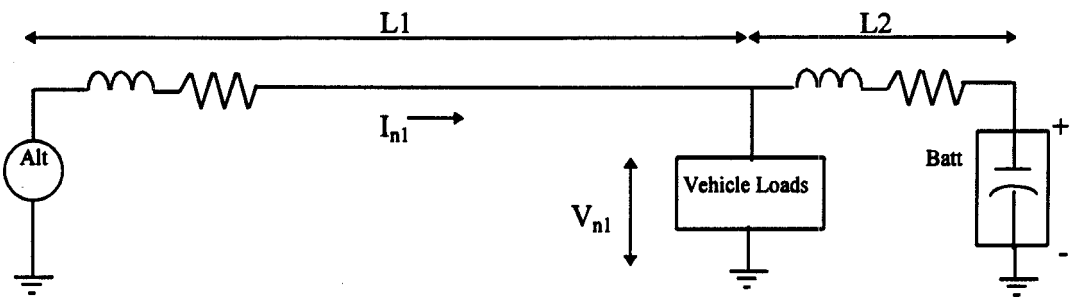
In reducing the electrical noise and stress generated by the charging system a dedicated cable has been used for charging and starting. All electrical systems are supplied directly from the battery, which provides suppression of the electrical noise.

Ensuring all loads come from the battery source considerably reduces the voltage range at the components and minimises the high voltages (typ. 14 - 15v) generated by the charging system of the vehicle.

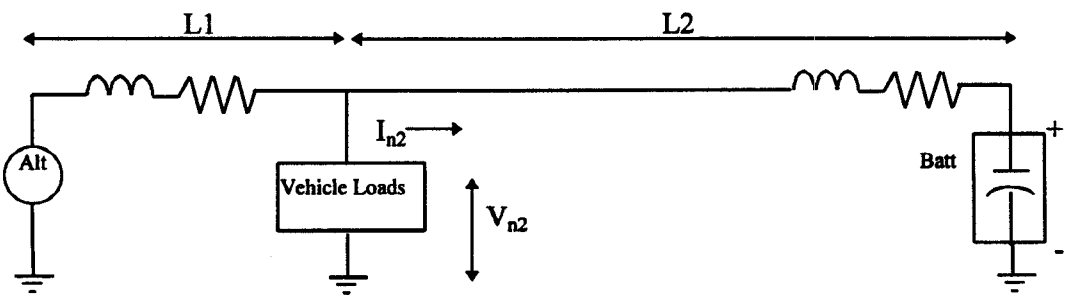
The charging cable was also partitioned away from the vehicle wiring system and components giving increased immunity from Electromagnetic coupling (see fig 1. on page 6).

Robustness Thinking:





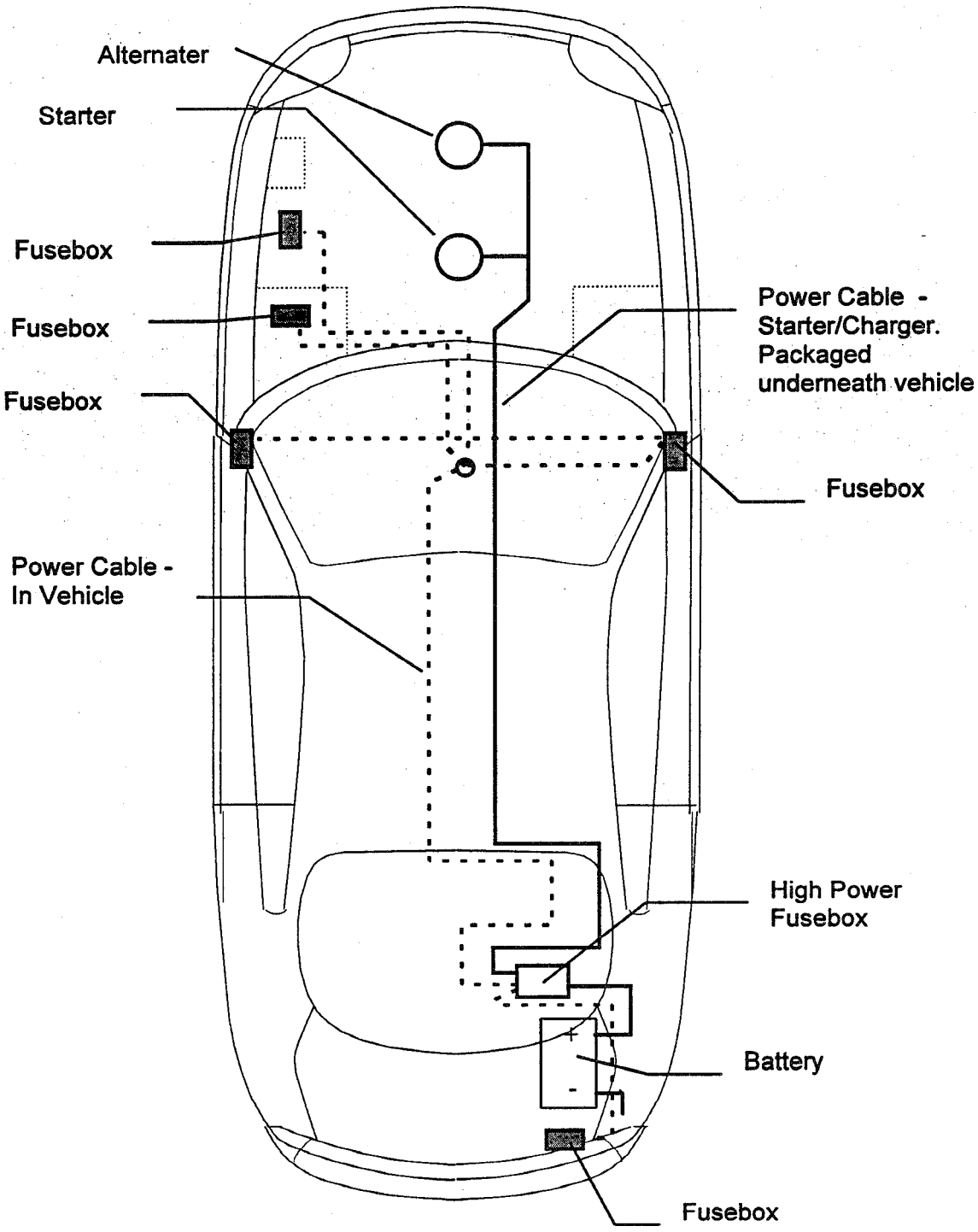
(Front Battery Application)



(Rear Battery Application) $V_{n2} > V_{n1}$

V_n = Voltage Noise (AC Ripple, DC volts)

Fig 1. Fusebox and Power Cable location



3.2. Some Wiring Information

The XK8 has approximately 1.6 km of cable.

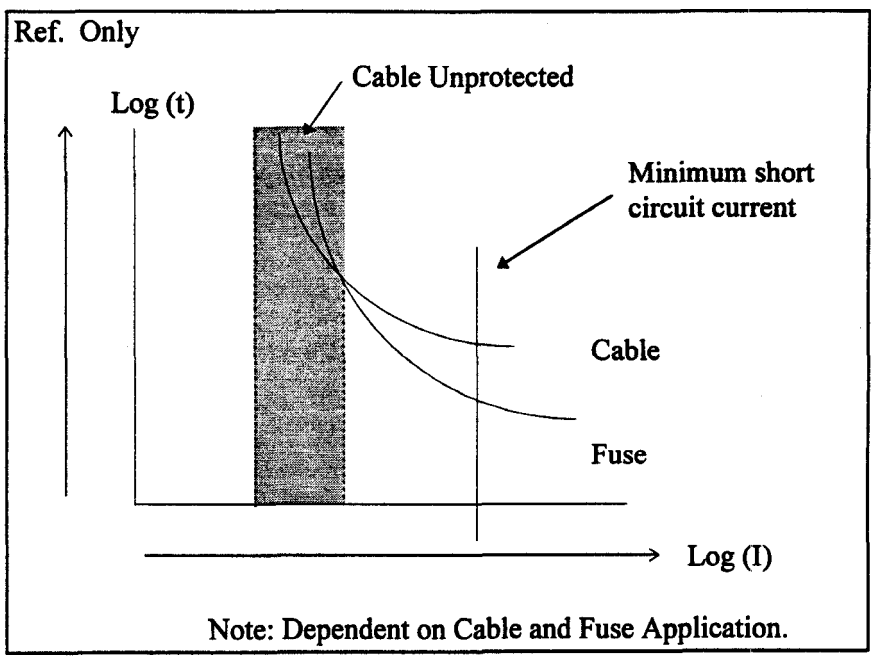
Signal Cables	Power Cables
approx. 1.26 km	approx. 3.4 km
79% of Total Cable	21% of Total cable

3.3. Fusing

The XK8 uses 79 Standard fuses (ATO®) and 3 MEGA® fuses. The vehicle adopts a zone based fusing architecture consisting of 5 fuseboxes (See Fig 1. on page 6). Zone based fusing indicates that vehicle loads are supplied from a local fusebox, the simplest zoning of a vehicle is to divide the car in to four corners.

The boxes have been supplied via a large diameter cable giving very little common mode resistance back to the battery. This architecture provides the following benefits:

- Increased Resistance to EMC.
- Increase in fault current ensuring very fast fuse blow times, this avoids operating the cable and fuse in undesired time/current areas (I/t). (Lower resistance between fuse and load)



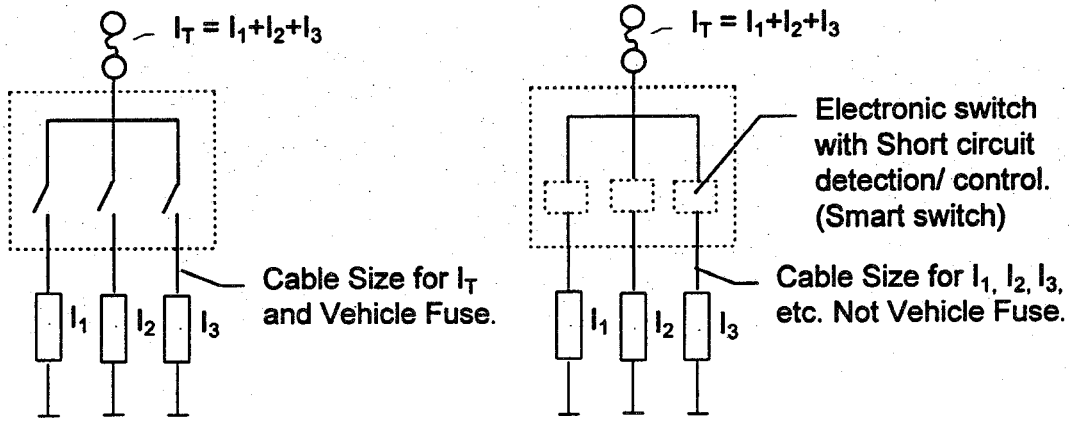
- Allows smaller Gauge cable to be used.
- Shorter Cable length.
- Reduction in number of circuits sharing a fuse.
- Reduced number of interconnects.
- Increased resistance to Electrical disturbance.
- Allows Relays to be packaged in fusebox - remote switching (No waterproof relays required, brackets, etc).

The XK8 has full circuit protection. The battery cable fusing has been achieved by the use of MEGA® Fuse. A combined 500A fuse consisting of two 250A devices has been used for starter circuit/Battery protection.

3.4. Circuit Protection Integration

The fuse count has been kept to a reasonable level despite minimising the use of common fuses on multiple circuits. This has been achieved in a number of ways on the XK8 vehicle:

- The Body Processor Module has 18 switched outputs supplied via 4 fuses, each output has Short circuit and overcurrent protection. This strategy provides fault isolation, avoiding vehicle fuse blow. This feature has also allowed smaller gauge cable to be used on the output wires since the Body Processor module provides isolation of the fault removing the need for the vehicle fuse to provide protection to these cables.



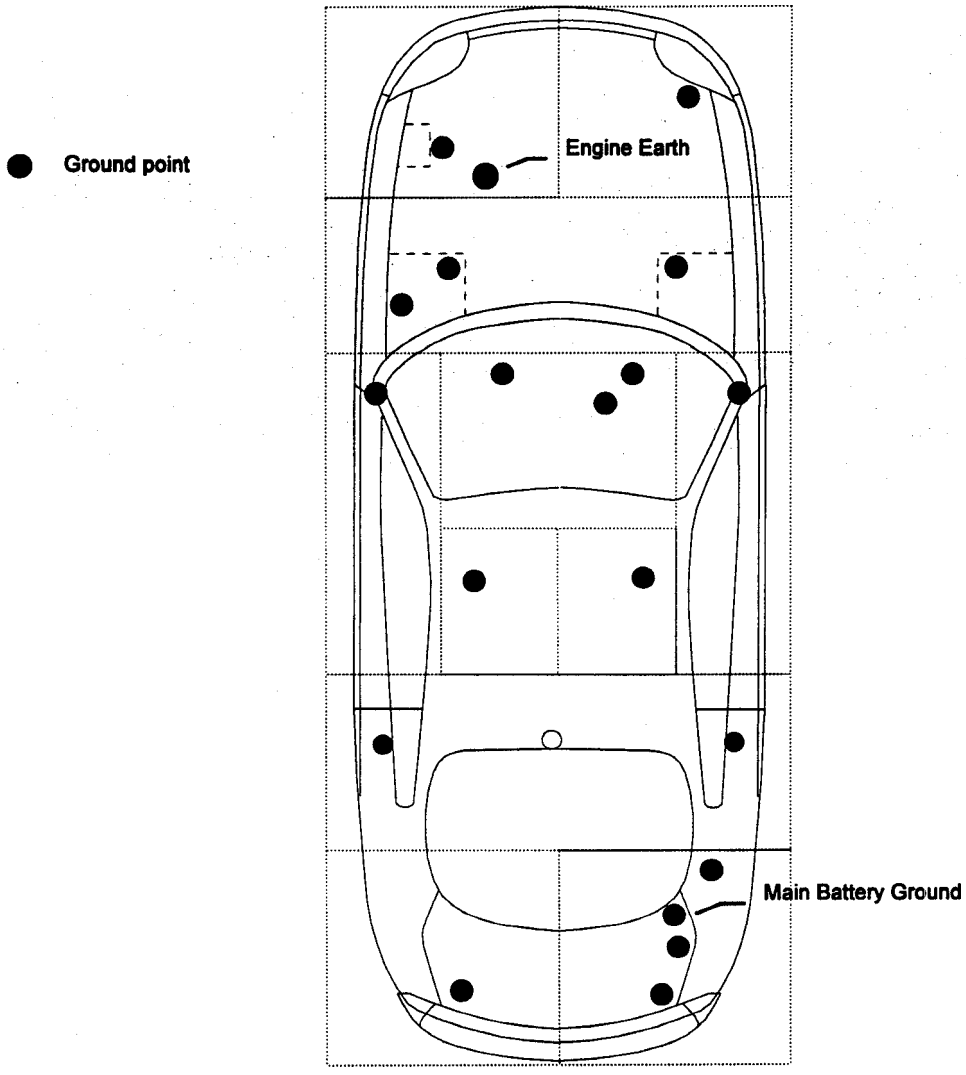
- The Security Locking Module has 5 switched outputs with Short circuit and Overcurrent protection.

- The use of software to control functions that have traditionally required thermal circuit protection devices or slow blow fuses. The following systems have had this feature since launch of the XJ6 Saloon introduced at 1993 model year.

  Wiper Motor - Software stall protection.
  Window lift - Software stall protection on Global close/Open.
  Door locking - Software stall/door lock cycling protection.
  Seat Movement - Software Load management/stall protection.

3.5. Grounding

The XK8 uses 21 ground points. The vehicle grounding has been partitioned into a zone based architecture. The grounding has also been classified into categories to reduce electrical disturbances on the grounding implementation. In general noisy 'Source' circuits have been separated from signal 'Receptor' circuits. The use of zone based grounding increases the vehicle resistance to EMC/electrical disturbances.



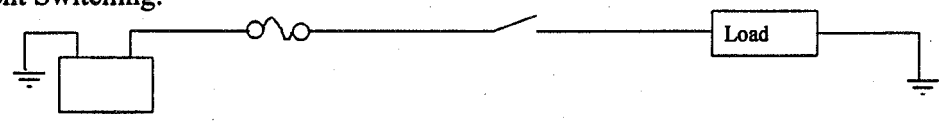
Benefits:

- Allows smaller gauge cable to be used.
- Shorter cable length.
- Reduction in number of circuits sharing a ground points.
- Reduced number of interconnects.
- Increased resistance to electrical disturbance.

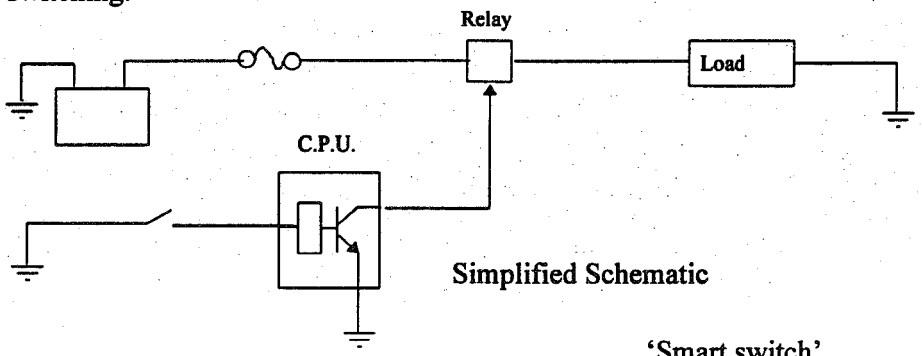
3.6. Remote Switching

Jaguar has utilised remote switching since the introduction of the XJ6 saloon introduced at 1985. This was possible with the introduction of low current switching technology and the use of a Central Processor Unit to control the vehicles Body System electronics, these can be loosely defined as non driver functions operated by the driver or passenger.

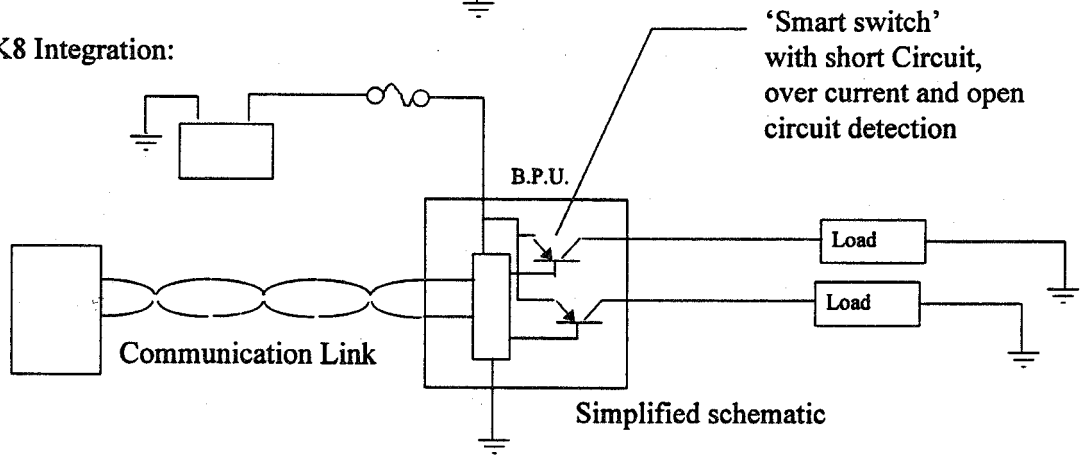
High current Switching:



Low current switching:



XK8 Integration:



The XK8 however has had a higher level of integration of remote and Smart switching into the following modules. This is a result of the location of the six control modules (Functional partitioning).

2 off Door module (Mixed Technology)
2 off Seat Module (Mixed Technology)
Security Locking Module (Mixed Technology)
Body Processor Module (Mixed Technology)

This leaves a total relay count of around 30..

- 16 Packaged in fuseboxes.
- Up to 12 Standard Relays located in harness.
- 5 Micro Relays located in harness.
- No Waterproof relays required.

Reducing Harness weight, Wiring size, cable length, packaging space and reduction in relay noise.

3.7. Signal Analysis

All modules were designed to ensure that all signals have an active threshold of 10 mA. This greatly increases the resistance to EMC, electrical disturbance and leakage currents arising with age of the vehicle. Sensitivity analysis was used to consider what impact the wiring, connectors and switch gear may have on the Active and In-Active margins of each modules input circuitry, considering: ageing, wear, Battery voltage, Ambient temperature, tolerance, component interaction on fuse and ground networks, etc.

Emphasis has then been placed on signals/signal types that do not comply with the minimum current rule requirement, allowing greater attention to be given to those circuits, e.g. twisted pair, shielding, cross coupling, filtering, special attention to terminal plating and connector application, etc.

4. Summary and Conclusion

Jaguar has demonstrated, by the innovative use of its design rules and circuit analysis methods, that real benefits can be achieved. This is mainly evident through the significant reduction of late changes to the electrical distribution system of XK8 over previous vehicles. Undoubtedly this approach, coupled with systems engineering disciplines, has kept the development costs manageable, maintained the quality attributes, and supported effective validation of the complex vehicle systems that depend on the EDS. XK8 is the most advanced vehicle Jaguar has ever produced, and despite this, it is the most successful engineered, electrical distribution system ever undertaken. We expect that this confidence is further vindicated by customer satisfaction measures and reduction of warranty costs during full volume production.